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UNIGAS®

TECHNICAL NOTES ON BURNER SYSTEMS

M12902CA Rev. 0 09/95

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UNIGAS burners are extremely versatile. Areas of application include process combustion plant, district heating schemes right down to individual domestic use.

The well equipped **UNIGAS** laboratory carries out matching tests on all well known heating appliances from both foreign and home markets. Because of this they have a first class understanding of current market requirements and are able to offer efficient, energy saving burners for all applications together with the appropriate control panel, oil handling unit or gas train.

UNIGAS are proud to have supplied many thousands of burners which are currently operating throughout the world.

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TECHNICAL NOTES ON THE OPERATION OF LIQUID FUEL BURNERS

1.INTRODUCTION

In heating plant, whether it is for domestic use or in an industrial process system, the equipment used for storage and delivery of the burner fuel does not always receive at the design stage, let alone during operation, the necessary care to ensure correct operation. This can lead to problems which, even if discovered quickly, can cause plant stoppages and production delays which can amount to considerable economic loss.

The following notes summarise calculation procedures to establish the dimensions of burner fuel oil supply equipment with the intention of providing the criteria for the rational and economic use of plant and fuel at a time when the decreased availability of energy sources makes necessary the use of higher viscosity fuel oils.

2. BURNER OIL SUPPLY OPTIONS

Burner supply systems depend on several items such as distance between burner and oil tank, oil characteristics and building layout.

The following are the four basic schemes as shown in Figs 1 to 4:
- Gravity Feed
- Syphon Feed
- Suction Feed
- Ring Main Feed

Below, we examine the functions of the principal elements in the fuel supply line and the problems they can cause when not operating correctly:

1) **Non-return Valve:** this serves to prevent the vertical section of the oil line emptying - it is unnecessary in a gravity feed system. If this valve is not operating correctly it can cause the whole oil feed line to empty when the burner or circulation pumps are stopped. This will lead to long delays whilst the fuel is re-instated if those periods are longer than normal pre-purge periods, the burner will stop repeatedly until the line is completely full. If the pump runs dry for long periods it can cause rapid wear and tear of the pump.

2) **FIRE SAFETY VALVE:** this is used as a safety measure, in the event of serious problems or a fire. It will immediately interrupt the flow of fuel to the burner. In in the event of an emergency its operating device must be easy to reach and therefore, must be placed away from the boiler and the oil tank.

3) **Automatic Cut-off Valve:** this is installed to prevent leaks in the oil supply line causing flooding of fuel from the tank. The device must be controlled by the burner, electrical connection or by the pressure created by the suction of the pump, such a device is not necessary when the burner is installed higher than the fuel tank. The valve prevents leakage in the event of damage to the line, and, if not operating correctly, can cause fuel starvation to the burners, which will lead to plant failure.

4) **Isolating Valves:** these facilitate disconnection of the oil line from the burner during maintenance or replacement without the need to drain the tank or oil line completely.

5) **Line Filters:** these are used to intercept any impurities in the fuel which could damage the pump, valves or burner nozzles.
There are two basic types of filter:
a) a screen of metal or synthetic material acting as a filter usually in the form of a drum.
b) combs made up of a series of steel plates interspersed with another series of steel plates attached to a central axis. Filtration occurs due to the rotation of the moveable plates by a handle on the central axis, filtering out the majority of the impurities.

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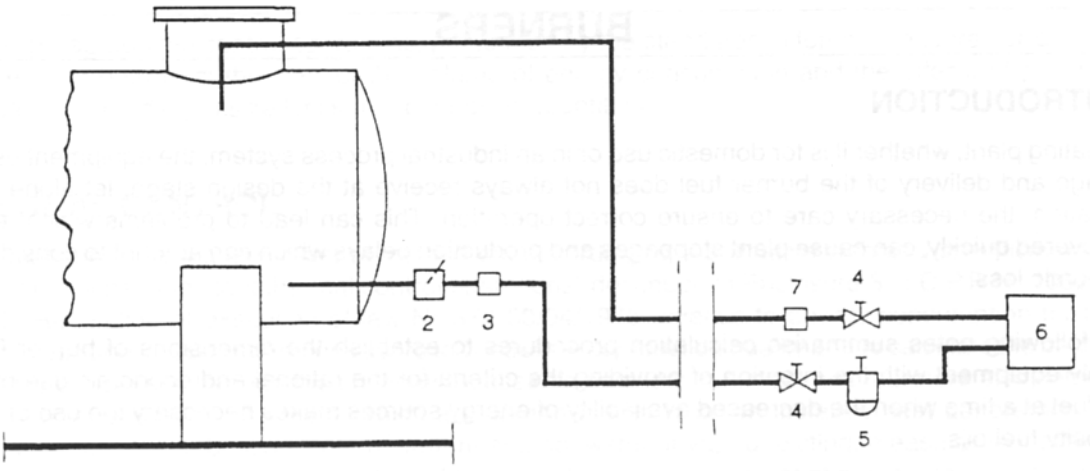

Figure 1 - Gravity Feed

1) Non-return valve
2) Fire Safety valve
3) Cut-off valve
4) Isolator valve
5) Line filter
6) Burner pump
7) Non-return valve
8) Vent line
9) Water trap
10) Auxiliary pump for main feed

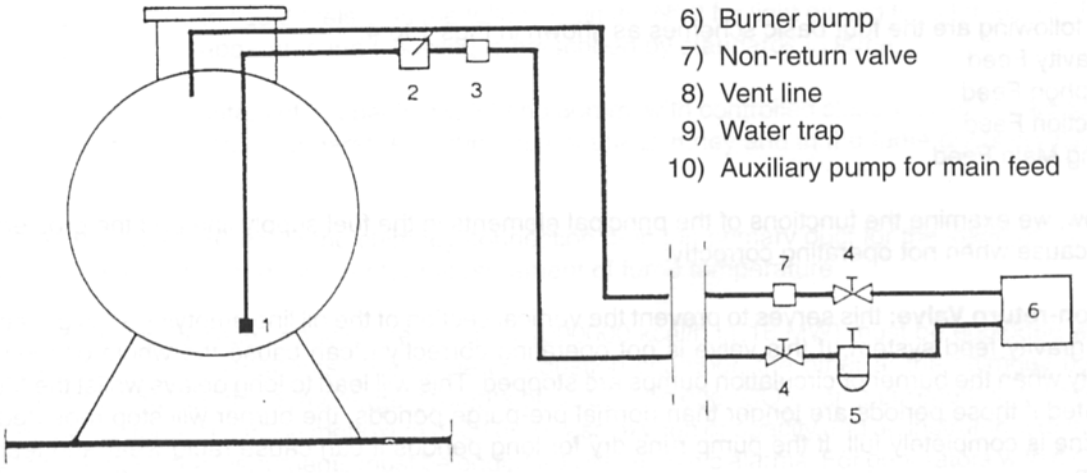

Figure 2 - Syphon Feed

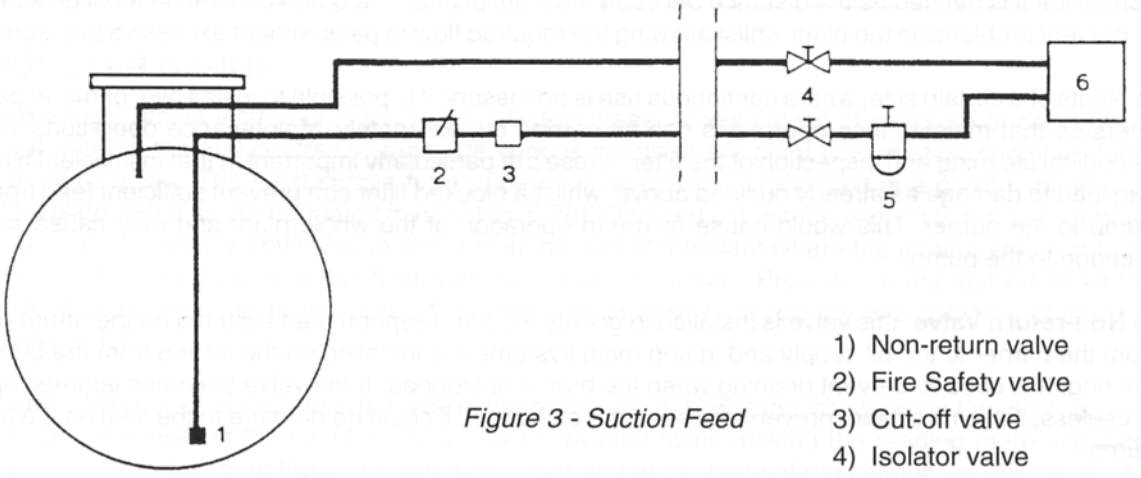

Figure 3 - Suction Feed

1) Non-return valve
2) Fire Safety valve
3) Cut-off valve
4) Isolator valve
5) Line filter
6) Burner pump
7) Non-return valve
8) Vent line
9) Water trap
10) Auxiliary pump for main feed

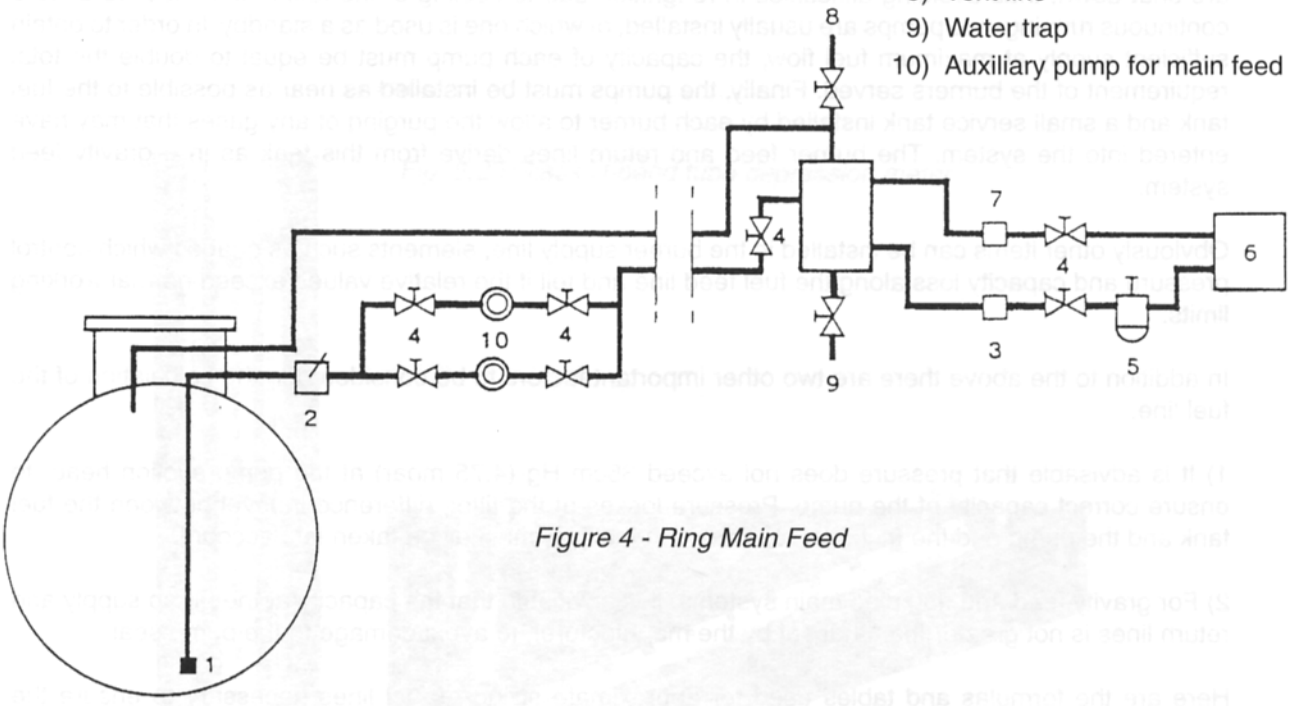

Figure 4 - Ring Main Feed

For screen filters, the grade of filtration is defined as the number of mesh squares per cm^2 whilst for the comb filter it is defined as the distance between the steel plates. The grade of filtration must be sufficient to prevent problems in the plant whilst allowing the required flow to pass without excessive pressure loss.

In plants of a certain size, where continuous use is necessary, it is possible to install two, or more, parallel filters so that maintenance operations can be carried out alternately. Maintenance operations include periodical cleaning and inspection of the filter. These are particularly important in that insufficient filtration can lead to damage as already outlined above, whilst a blocked filter can prevent sufficient feed from the pump to the burner. This would cause failure in operation of the whole plant and may cause serious damage to the pump.

6) **Non-return Valve**: this valve is installed in gravity feed and syphon feed systems on the return oil line from the burner to the oil supply and in ring main systems it is installed on the oil line from the burner to the ring. It is used to prevent draining when the burner is stopped. If the valve becomes jammed open it is useless, if it jams closed, preventing the return of the fuel, it could do damage to the seal on the burner pump.

7) **Booster Pump**: these are used when the burners are remote from the fuel tank or the tank is situated much lower than the building. The pump is electrically connected to ensure that it operates when the burners are running. For heavy fuel oil plant it is advisable that the pump operates even when the burners are shut down, thus avoiding difficulties in re-ignition due to cooling of the fuel in the lines. To ensure continuous running, two pumps are usually installed, of which one is used as a standby. In order to obtain sufficient supply at maximum fuel flow, the capacity of each pump must be equal to double the total requirement of the burners served. Finally, the pumps must be installed as near as possible to the fuel tank and a small service tank installed by each burner to allow the purging of any gases that may have entered into the system. The burner feed and return lines derive from this tank as in a gravity feed system.

Obviously other items can be installed in the burner supply line, elements such as guages which control pressure and capacity loss along the fuel feed line and tell if the relative values exceed normal working limits.

In addition to the above there are two other important factors to be considered in the calculation of the fuel line.

1) It is advisable that pressure does nol exceed 35cm Hg (4.75 mbar) at the pump suction head, to ensure correct capacity of the pump. Pressure losses at the filter, difference in level between the fuel tank and the pump and the frictional resistance in the line, must all be taken into account.

2) For gravity feed and ring pipe main systems, it is advisable that the capacity at the pump supply and return lines is not greater than that set by the manufacturer, to avoid damage to the pump seal.

Here are the formulas and tables used for approximate sizing of fuel lines necessary to ensure the desired flow rate is achieved.

Note that the fuel flow is in kg/h, viscosity is in centistokes, density, s, is obtained from the viscosity/ temperature diagram and from Table 1, according to the temperature under consideration.
The velocity of the fuel in the pipework, in m/s, is obtained using:

$$v = \frac{Q}{2.8\ sd^2}$$

where d = diameter of fuel line in mm which is, at this point, an estimate. Once the velocity has been obtained, the Reynolds number of the flow in question can be obtained using:

$$Re = \frac{1000\ d\ v}{K}$$

If the Reynolds number is greater than 2100 the fuel flow is turbulent and the Resistance Factor is

obtained from Table II if, however, Re is less than 2100 the flow is laminar and F is obtained using:

$$F = \frac{16000}{Re}$$

thus the fall in pressure loss in the pipework in m^3 can be calculated using:

$$\Delta p = \frac{0.21\ s\ v^{\ 2}\ LF}{d}$$

where L is equal to a fictitious length obtained by the geometric length of the pipework plus the equivalent length of the various valves, section changes and changes of direction etc. in the fuel line according to Table IV F must be corrected in relation to material and condition of tubing, where necessary, using the coefficients shown in Table III.

The loss in capacity due to the filter must be taken into account. This figure is obtained from the manufacturer's data (this usually has a value of between 0.4 and $1m^3$ depending on the type of fuel flow and the condition of the filter). The difference in level between the burner and the fuel tank must also be considered. If the fuel tank is situated lower than the boiler (suction feed), this difference, in metres, is mutiplied by fuel density and added to Δp.

If the fuel tank is situated higher than the burner the difference in metres x fuel density must be subtracted from Δp. Where there is more than one burner served and a pulverizer installed, the pump must operate at sufficient pressure to supply these, this figure, again in m^3, added to the Δp figure obtained.

At this point, using flow Q in kg/h and total Δp in m^3 the pump rating in Watts can be obtained using:

$$N = \frac{Q\Delta p}{367.\ 2n}$$

where n = pump output and is between 0.4 and 0.6

Remembering that pumps of mechanical atomising burners require a flow greater than that burnt at the nozzle and the surplus is sent back to the fuel tank via the return line. The total flow used in the line calculations is, therefore, the total flow from the pump, including return flow, and not just the fuel burnt.

Normally the return line is of the same diameter or slightly smaller than the feed line.

To conclude, excluding fuel compression, the calculation of the Δp of the tubing can lead to two possibilities:

1) Δp at exit of line filter less than $4m^3$; the burner/s can be fed directly from the fuel tank, each having its own suction or gravity feed line.

2) Δp greater than $4m^3$: ring pipe feed, auxiliary pumps situated as close to the fuel tank as possible, are necessary.

Calculation Examples:

1) Required flow = 280 kg/H; s = 0.840; K = 3cst (light oil), underground tank with feed 2m from the level of the pump, steel line length l = 12m with 3 bends, 2 isolating valves, 1 interception valve, line filter ($\Delta p=6m^3$) Fixed d = 25 mm:

$$v = \frac{280}{2.8 \times 0.84 \times 625} = 0.19 \text{ metres/second;}$$

$$Re = \frac{1000 \times 25 \times 0.19}{3} = 1583$$

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Table 1 Density correction coefficients at 15°/4°C for 1°C

Density a 15°/4°	Corr. Coeff.	Density a 15°/4°	Corr. Coeff.
0.7647 ÷ 0,7757	0,00076	0,8021 ÷ 0,8279	0,00068
0,7758 ÷ 0,7866	0,00074	0,8280 ÷ 0,8594	0,00067
0,7867 ÷ 0,7984	0,00072	0,8595 ÷ 0,9245	0,00065
0,7985 ÷ 0,8020	0,00070	0,9246 ÷ 1,0243	0,00063

Note: For temperatures less than 15°C the corrections are added to density, for temperatures greated than 15°C the corrections are subtracted.

Table 2 Turbulent flow in new steel tubing resistance factors.

Re	F	Re	F	Re	F	Re	F	Re	F
2101	14,1	3380	12,1	6294	10,1	14640	8,1	54790	6,1
2160	13,9	3572	11,9	6765	9,9	16240	7,9	65805	5,9
2261	13,7	3780	11,7	7287	9,7	18095	7,7	80255	5,7
2369	13,5	4006	11,5	7869	9,5	20265	7,5	99665	5,5
2485	13,3	4252	11,3	8519	9,3	22830	7,3	126480	5,3
2608	13,1	4520	11,1	9248	9,1	25875	7,1	164830	5,1
2741	12,9	4812	10,9	10070	8,9	29535	6,9	222055	4,9
2833	12,7	5131	10,7	11000	8,7	33980	6,7	312200	4,7
3036	12,5	5482	10,5	12055	8,5	39430	6,5	464700	4,5
3201	12,3	5868	10,3	13260	8,3	46215	6,3	749325	4,3
3380		6294		14640		54790		1363135	

Table 3 Resistance factor corrections for condition of pipe.

Copper, brass	0,9
Steel, cast iron (new)	1,0
Cast iron (used)	1,4
Steel (used)	1,6

Table 4 Equivalent lengths for concentrated resistance (per metre of tubing).

mm / inches	13 ½"	25 1"	38 1 ½"	51 2"	63,5 2 ½"	76 3"	102 4"
Gate valve (open) or isolating valve	0,2	0,2	0,2	0,3	0,3	0,6	0,6
Right angle valve (open)	4,5	5,5	6,7	8,2	9,8	12,5	16,2
T, branch copper	1,7	2,2	2,9	3,7	4,4	5,2	6,7
T, main copper	0,8	0,9	1,1	1,2	1,4	1,5	2,1
Elbow	1,7	2,2	2,9	3,7	4,4	5,2	6,7
Diameter change:							
d/d' = 4	0,5	0,7	1,1	1,5	2,0	2,5	3,4
d/d' = 2	0,7	0,9	0,9	1,2	1,2	1,8	2,1
d/d' = 1,33	0,2	0,2	0,2	0,3	0,3	0,6	0,6
d/d' = 0,75	0,2	0,2	0,2	0,3	0,3	0,6	0,6
d/d' = 0,5	0,2	0,3	0,3	0,6	0,6	0,9	1,2
d/d' = 0,25	0,4	0,6	0,6	0,9	0,9	1,2	1,5
90° bend	1,3	1,5	1,8	2,1	2,5	3,0	3,7

Note: For turbulent flow add the calculated resistance length to geometric length, for laminated flow, calculated resistance can be disregarded.

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This means the flow is laminar, thus the resistance of valves, bends, etc., is disregarded, line length is, therefore:

$12 + 2 = 14m; \quad F = \frac{16000}{1583} = 10.1$

$\Delta p = \frac{0.21 \times 0.4 \times 0.036 \times 14 \times 10.1}{25} = 0.036 m^3$

Then we must consider:

Δp for difference in level = $2 \times 0.84 = 1.68 m^3$ and
Δp filter = 0.6m therefore the total capacity lost between the pump and the dischange is:
Δp [o] $= 0.036 + 0.6 + 1.68 = 2.316 m^3$

Remembering that Factor F will increse over time due to the deterioration in the internal surface of the pipe (Tab.III). The burner in question can be fed by suction using the line calculated as above.

2) Ring main steel line to feed three liquid fuel oil burners (s = 0.92, K= 125cst), required flow = 2000kg/h, (including return) 150m with 3 bends, 2 dampers, 4T in direct branch, IT in diverted branch.
Fixed d =1 1/2" (38 mm)

$v = \frac{2000}{2.8 \times 0.92 \times 1444} = 0.53$ metres/second

$Re = \frac{1000 \times 38 \times 0.53}{125} = 161$

$F = \frac{16000}{161} = 99.4$

$\Delta p = \frac{0.21 \times 0.92 \times 0.28 \times 150 \times 99.4}{125} = 6.45 m^3$

$N = \frac{2000 \times 6.45}{367.2 \times 0.5} = 73$ Watt

Based on the position of the burner outlets, residual capacity must be controlled to ensure that it does not exceed the acceptable level for the burner pumps. The return line must also be considered in calculating line dimensions, it is preferable that the whole section can carry the total flow required in order to maintain circulation even when the burners are shut down. When installing the pump it is advisable to leave a certain amount of capacity in reserve to cope with the increase in loss of capacity over time due to deterioration of the internal surface of the line.

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SIZE AND CHOICE OF BURNER

SIZE OF GAS LINES AND ACCESSORIES

The choice of a burner requires the knowledge of certain fundamental data:

1. Capacity in kcal/h of the boiler furnace
2. Counter pressure in combustion chamber, also defined as capacity lost (Δp) to products.
3. Minimum gas pressure at meter exit or entrance to boiler house.
4. Minimum heat capacity of gas used.
   Calculation procedures are divided into four parts:
   1. Choice of burner
   2. Choice of gas train
   3. Choice of components
   4. Where necessary, calculation of diameter and capacity loss of pipework.

PART ONE

CHOICE OF BURNER

Necessary data:

1) Boiler furnace capacity in kcal/h
   (where capacity is expressed in kW multiply by 860, kcal/h = kW x 860)

2) Resistance in combustion chamber

3) Gas flow = furnace capacity : Minimum heat capacity (8570 kcal/Nm3)

Example:

Furnace capacity	=	kcal/h 428000
Gas flow	=	50 Nm^3/h
Counter pressure in combustion chamber	=	4 mbar

Procedure:

Select burner model from the performance table:

BURNER MODEL		P1M25	P3M40	P5M40	P60M50	P70M50
kW	min	116	151	267	348	465
kW	max	232	348	524	698	1046
kcal/h	min	100,000	130,000	230,000	300,000	400,000
kcal/h	max	200,000	300,000	450,000	600,000	900,000

As you can see there are two burner models that cover the required capacity:

P5M40 (gas train from 1 1/2") and P60M50 (gas train from 2").

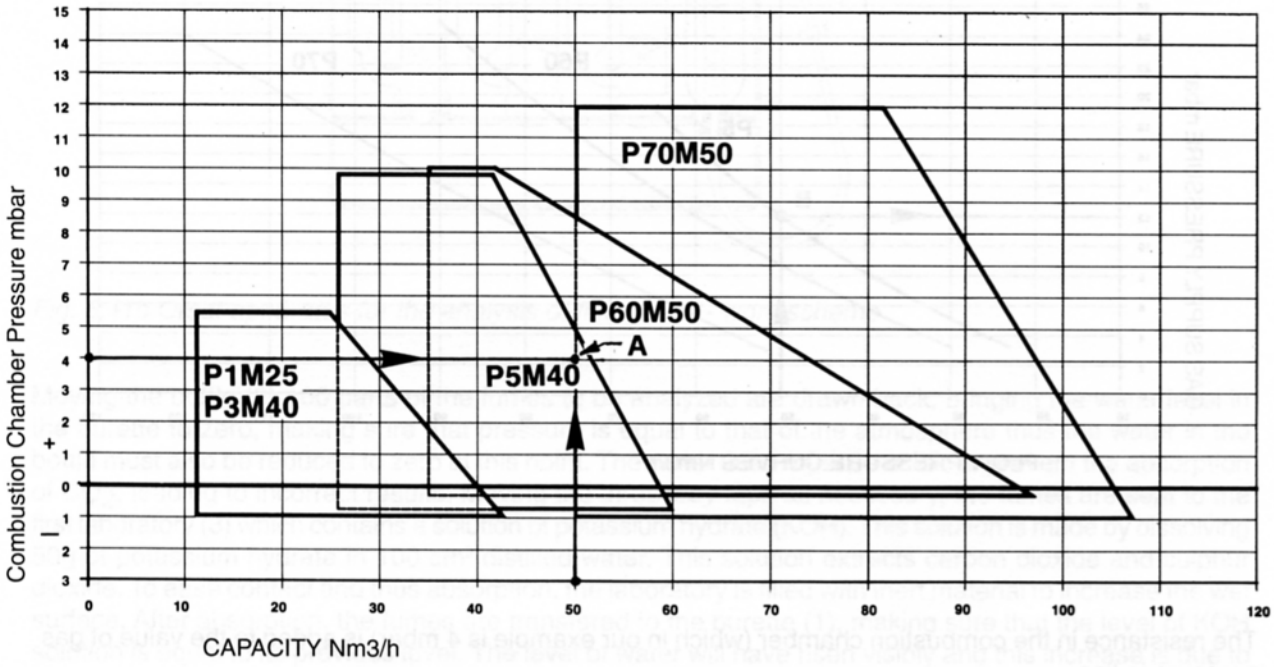
At this point it is necessary to verify whether the chosen burner model covers the required resistance in the combustion chamber.

Using the performance curves of the chosen burners, draw a vertical line corresponding to the gas flow (50Nm³/h and a horizontal line corresponding to the counter pressure (4mbar).

The capacity shown in all tables refers to methane gas with minimum heat capacity of 8570 kcal/Nm³ and zero resistance in combustion chamber.

Performance Curve Diagram

The point of intersection "A" determines which burner is suitable



PREFACE TO PARTS TWO AND THREE

The size and choice of gas train and accessories are based on the evaluation of total capacity loss, which must not exceed the minimum gas pressure available in the line.

It is, therefore, necessary to calculate all the following capacity losses:

1) Δp Burner including gas train
Δp Gas-pressure regulator
Δp Filter (only if not incorporated in gas pressure regulator)
Δp Fuel isolating valve (only if requested)

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PART TWO

Gas train

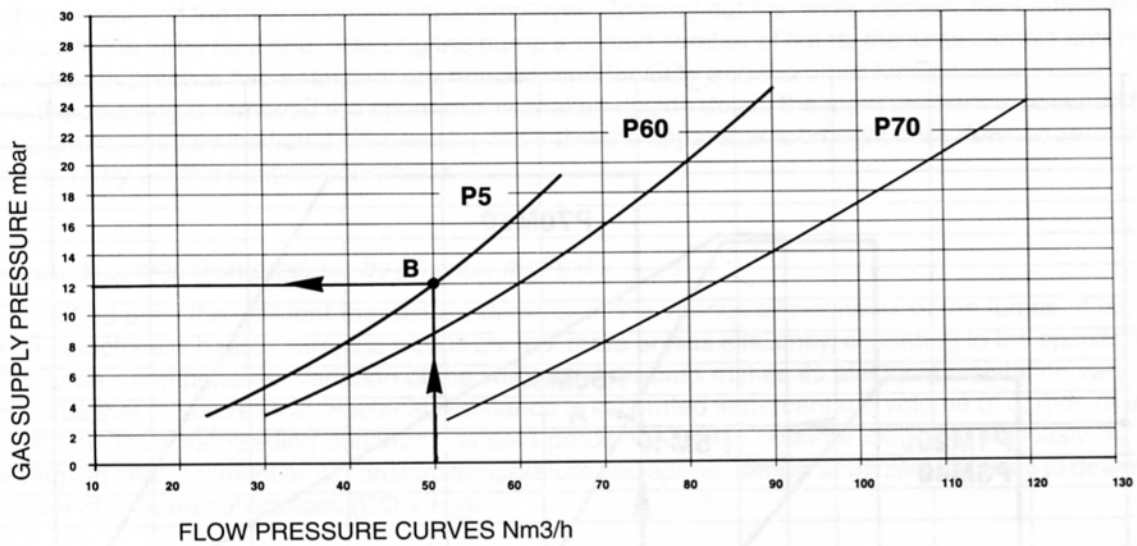
Necessary data: Flow in Nmc/h

Procedure:

$$\frac{\text{Furnace Capacity}}{\text{Lower heat capacity (kcal/Nm}^3\text{)}} = \text{Nmc/h } \frac{428500}{8570} = \text{Nmc/h } 50$$

(8570 methane gas)

On the pressure/flow diagram trace a vertical line corresponding to 50 Nmc/h and a horizontal line from the intersection with the curve P5 (B) to the gas pressure in line axis.



The resistance in the combustion chamber (which in our example is 4 mbar) is added to the value of gas pressure in line.

At this point the gas pressure necessary at entrance to the valves has been identified. That is the pressure loss (Δp) of the burner including valves and combustion chamber.

Gas train P5 (1/2) mbar 16 (12 + 4)

PART THREE

Choice of Components:

Gas Pressure Regulator:

The pressure loss due to resistance in burner is subtracted from the gas pressure available at inlet to system.

The remaining gas pressure is available for the pressure loss of other components.

Gas pressure to boiler = 20 mbar

Capacity lost products and burner = 16 mbar

Remaining available gas pressure = 4 mbar

Maximum loss of capacity of governor

with filter incorporated = 4/2 mbar = 2 mbar

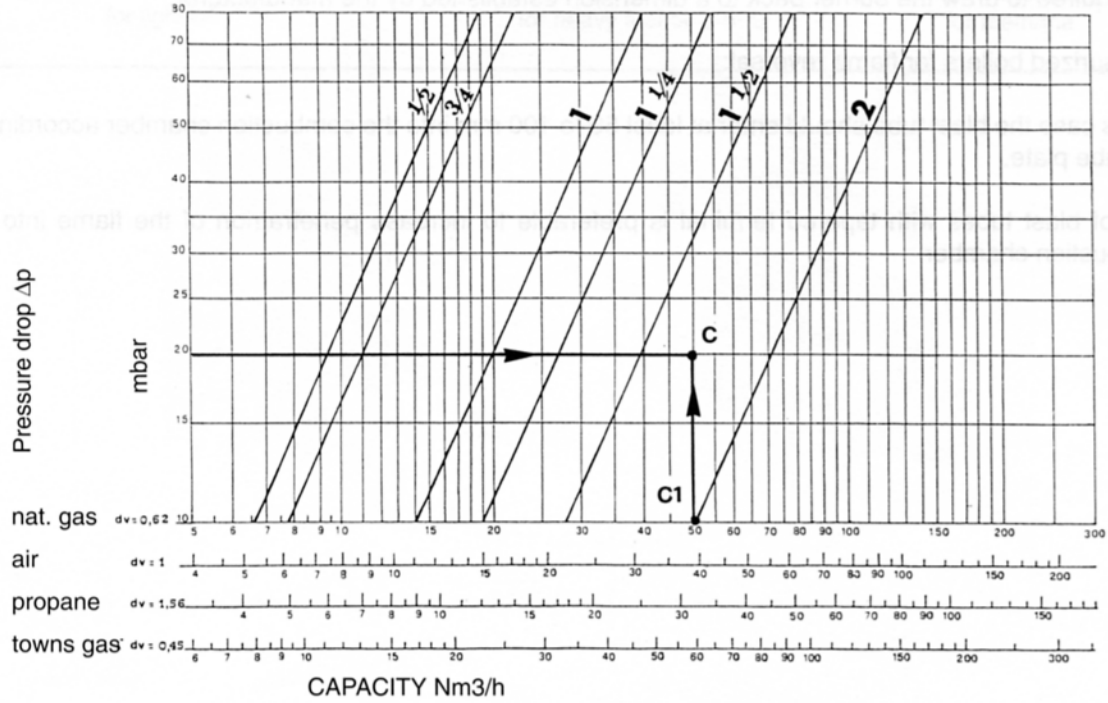
Trace, on diagram 1, a vertical line corresponding to 50Nmc/h and a horizontal line corresponding to capacity loss ie. 2 mbar.

The point of intersection of the two lines "C" determines the diameter of the governor with filter incorporated.

If the point of intersection of the two lines is,as in this case, between two curves, the governor with the larger diameter is chosen.

In our example, the govenor would have a diameter of 2" and a capacity loss of 1.0 mbar (Point C1).

1) For criteria of choice see Enclosure A
"Gas pressure regulators"



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Data Review (Parts Two and Three)

Δp Burner	12 mbar
Δp Products	4 mbar
Δp Governor with filter incorporated	1 mbar
Total capacity loss	17 mbar
Gas pressure to boiler house	20 mbar

As you can see the sum pressure losses does not exceed the available gas pressure, therefore, the results of the calculations are correct.

In the calculations, loss of capacity from the isolating valve and the anti-vibrating joint are not taken into account because these components cause insignificant losses as long as they are the same diameter as the filter and govenor used.

A fire valve, if used, should have a maximum capacity loss of 3 mbar.

CHOICE OF BLAST TUBE

To finish our work it only remains to determine the size of the blast tube.

To choose blast tube refer to manufacturer's instructions. If these are not available, size is determined using the following method:

Boilers in cast iron, boilers with three passes (with the first pass in the rear section):

The blast tube should enter into the combustion chamber no more than 100 mm, therefore, a spacer may be required to draw the burner back to a dimension established by the manufacturer.

Pressurized boilers for flame reversal:

In this case the blast tube should enter at least 50 to 100 mm into the combustion chamber according to the tube plate.

Use of blast tubes with tapered terminal is preferable to increase penetratrion of the flame into the combustion chamber.

Enclosure "A"

Gas Pressure Regulators

It is necessary to know that the choice of a gas pressure regulator is not only made in conjunction with pipework diameter of the gas train but, above all, according to the capacity loss
Δp resulting from Diagram 2.
Gas pressure regulators also work well with low pressure losses.
For best operation there should be a difference equal to twice the capacity loss (Δp), resulting from Diagram 2, between the inlet and outlet pressure.

1) Δp = Capacity loss as in Diagram 2
2) dp = Arithmetic difference between inlet pressure (Pe) and outlet pressure (Pu) is equal to capacity loss of burner including gas train, plus the resistance in the combustion chamber.

Example:
Inlet Pressure = 20 mbar
Outlet Pressure = 16 mbar
Flow Nmc/h = 50 methane gas

To determine the type of regulator necessary proceed as follows:

1) Calculate the fall in pressure dp = 20 - 16 = 4mbar

2) Calculate maximum pressure loss p = 4 : 2 = 2mbar

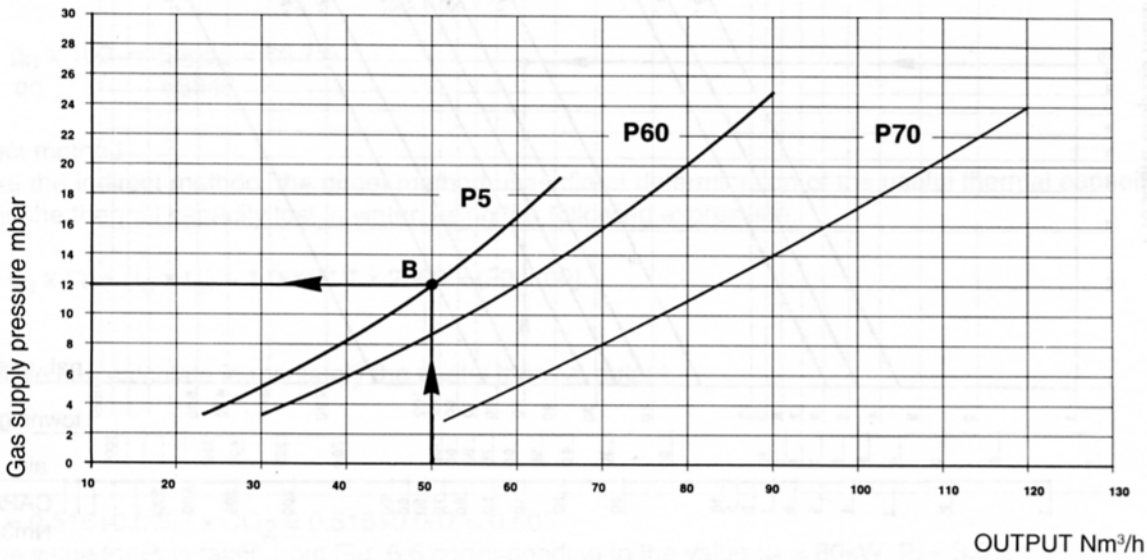
3) On the flow diagram trace a vertical line corresponding to 2 mbar of capacity loss (Δp)

Thus a suitable diameter for the regulator is obtained.
If the point of intersection, as in this case, is between two curves, the model with the larger diameter is chosen.

In this case the required regulator has a diameter of 2".

Pay attention to maximum inlet gas pressure which the pressure regulator can stand (see manufacturer's data).

Vent pipes are not necessary for pressure regulators with a double diaphragm. For regulators without a double diaphragm a vent pipe must be installed with a minimum internal diameter of 10 mm, protected at outlet with a metal flame arrestor, which should exit at a minimum distance of 1.5m from any opening or air supply point.



N.B. The diagrams and tables shown are of an indicative nature, in reality, choice of components is made with reference to catalogues supplied by manufacturers.

Enclosure "B"

Gas Filter

The gas supply line must be fitted with a suitable filter to guarantee filtration of particles with a diameter greater than 50 µm.

The capacity loss at the nominal flow of burner must be less than or equal to 1 mbar.

To establish the diameter of the filter proceed as follows:

Trace, on the diagram, a vertical line corresponding to gas flow and a horizontal line corresponding to pressure loss.

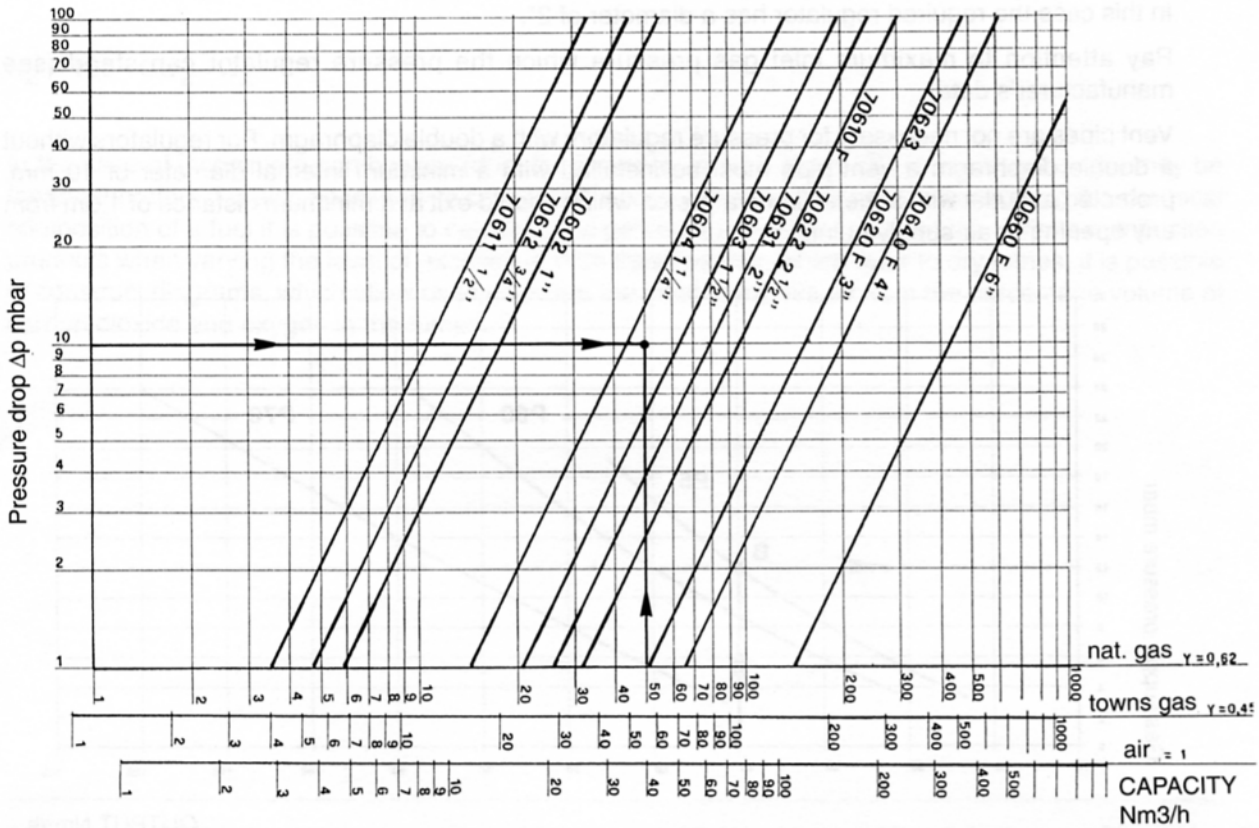
Example:

- Flow 52 Nmc/h

- Pressure loss 1 mbar

The filter must be chosen from those with a diameter greater than the point of intersection "D" of the two lines.

Diagram to determine capacity of gas fitter.



Enclosure "C"

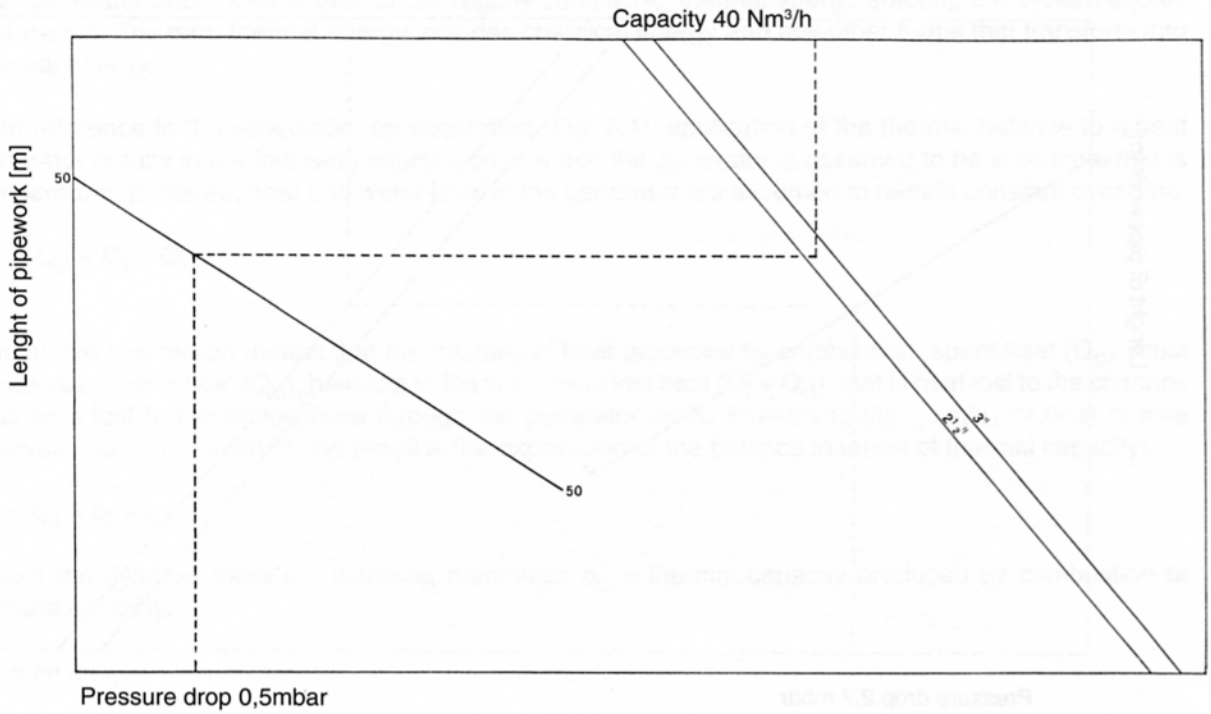
Gas Pipework

Necessary data:
1) Length of pipework
2) Flow in Nmc/h
3) Accepted level of pressure loss

Example No. 1

Known: Length of pipework 50m
Flow 40 Nmc/h
Pressure losses 0.5 mbar

The diameter of the pipework must be found. Proceed as shown in the following example:



Trace two vertical lines, one corresponding to pressure loss up to the intersection with the length line (Point A), the other corresponding to the flow.

Starting from Point "A" trace a horizontal line until it intersects the vertical flow line, thus establishing Point "B".

Point "B" determines the diameter of the pipework. If this point is between two lines the larger diameter is chosen, in our example a diameter of 3" would be chosen.

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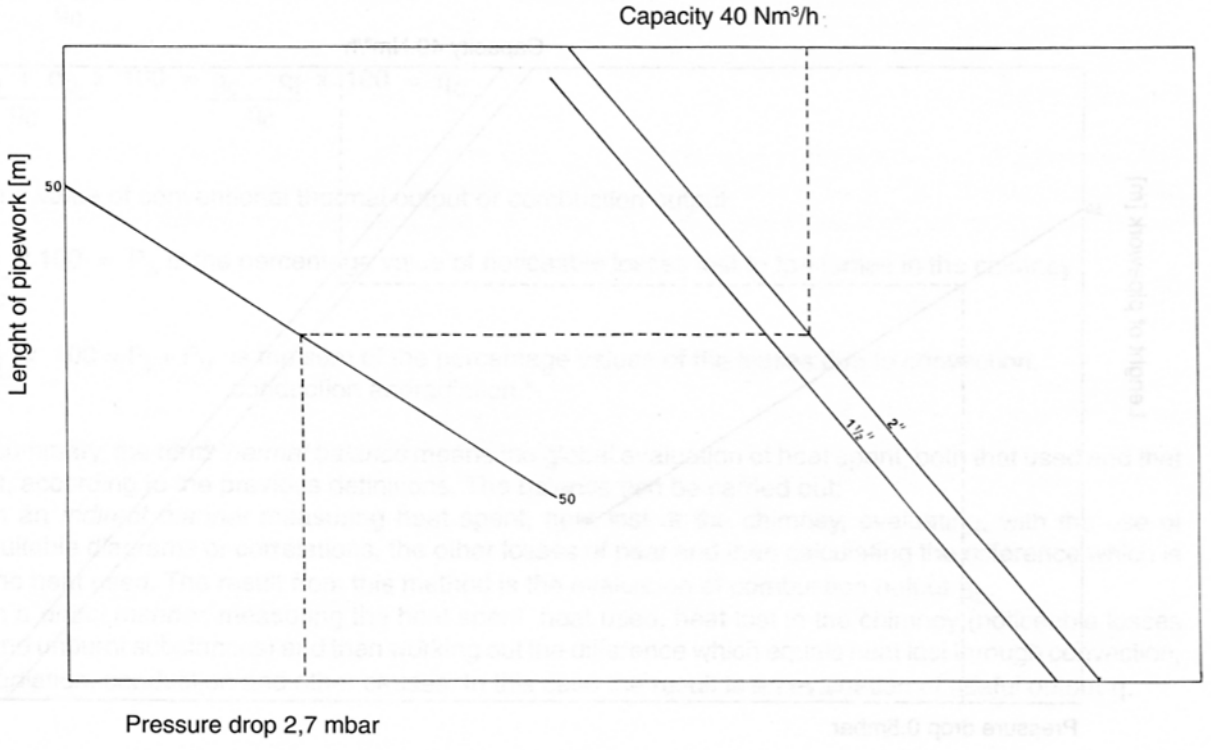
Example No. 2

Known: Length of pipework 50m
Flow 40 Nmc/h
Diameter 2"

The pressure loss must be found.

Proceed as shown in the following example:



Pressure drop 2,7 mbar

Starting from the flow line trace a vertical line to meet the diameter line (2"). (Point "B") From this point trace a horizontal line to meet the length line (Point "A"), from this point draw a vertical line downwards, thus identifying the pressure loss:

In this case the pressure loss is 2.7 mbar.

Diagram to determine pipe diameter, pressure drop, lenght and capacity of pipe

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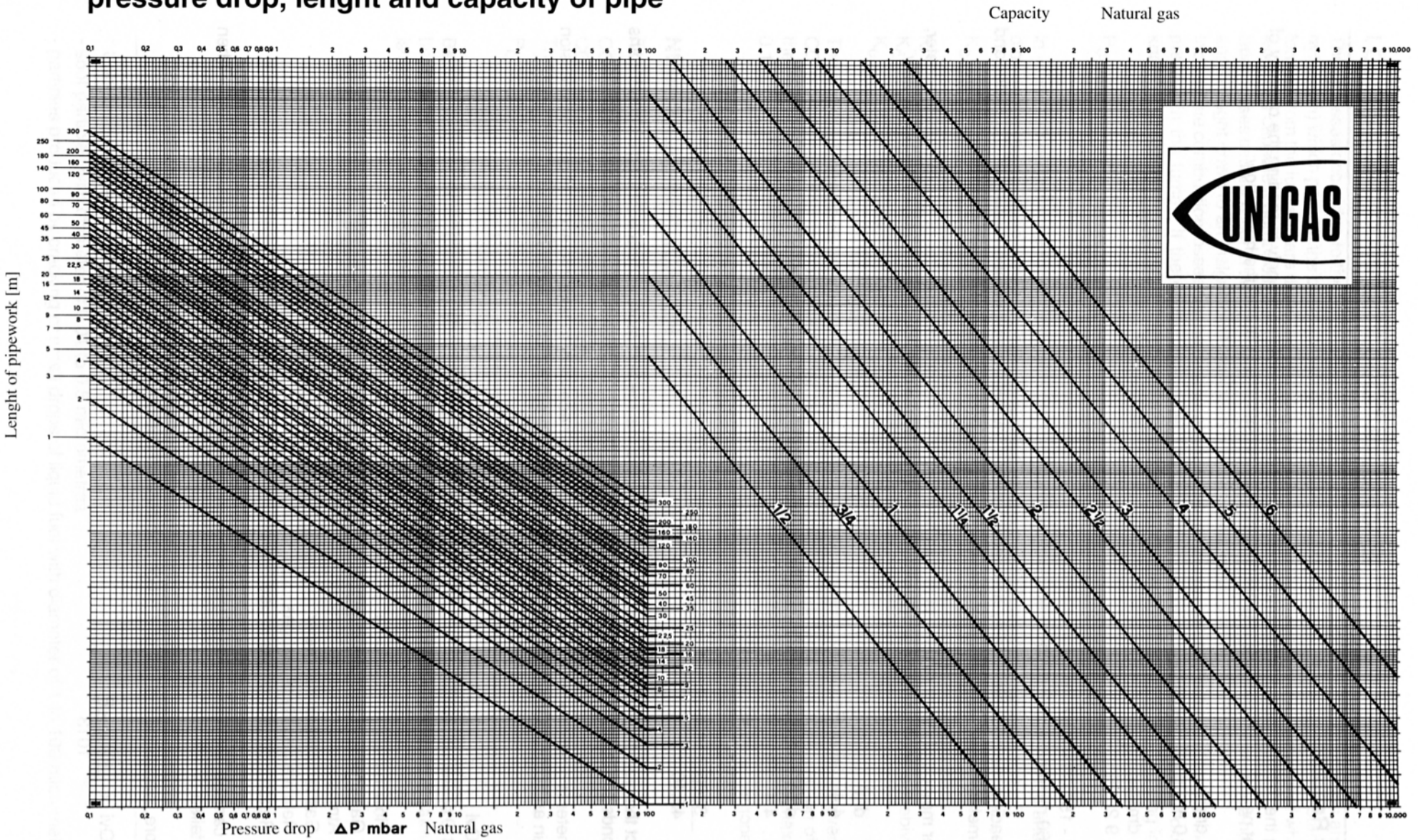
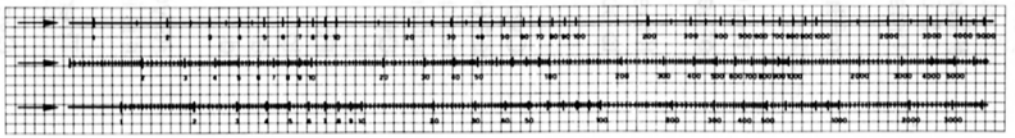


Air
Natural gas
L.P.G.



Capacity (Q) Nm³/h

GAS	Spec Wgt	Density	K
Air	1.29	1.00	1.00
Natural gas	0.84	0.65	1.24
L.P.G.	2.19	1.70	0.77

$$Q\,Air = \frac{Q\,Gas\,used}{K} \qquad K = \sqrt{\frac{Spec.\,weight\,air}{Spec.\,weight\,of\,gas\,used}}$$

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Enclosure "D"

Meter Reading

Among the various methods of meter reading, the one used most commonly is reading the quantity of gas that passes in 60 seconds and multiplying it by 60 minutes to obtain the hourly flow:

m^3 dm^3
1 5 7 . 0 5 Initial Reading

m^3 dm^3
1 5 7 . 9 2 Final Reading

157.92 - 157.05 = 0.87
0.87 x 60 minutes = 52.2 m^3/h

As a reading method this is fairly accurate though it involves simultaneous reading of the meter and chronometer.

Another method of meter reading is to time how long it takes for a cubic meter of gas to pass the meter, then divide the 3600 seconds which make up an hour by the time recorded to obtain the hourly flow.

m^3 dm^3
1 5 5 7 . 4 4 Initial Reading

m^3 dm^3
1 5 5 8 . 4 4 Final Reading
Time recorded = 45.40 seconds

$$m^3/h = \frac{3600}{45.40} = 79.29$$

The fact that you only have to watch the meter makes this method more accurate as long as hundredths of seconds are taken into account.

If the meter is positioned in a high pressure system it is necessary to take into account gas compression to obtain an accurate measure of flow. The formula to be applied is the following:

$$Qvc = Qvi \sqrt{\frac{1013 + P}{1013} \times \frac{Pb + P}{1013} \times \frac{288}{273 + tg} \times \frac{d}{d_r}}$$

where:
Qvi = Flow in measured volume
P = Gas pressure at meter in mbar
Pb = Atmospheric pressure in mbar
tg = Gas temperature at meter
d = Relative density of test gas
d_r = Relative density of gas in use

As you can see, the application of this formula involves the use of data which is impossible to know when it is installed on the plant.

Therefore, we advise the use of a much abbreviated and more practical formula:

$$Qvc = Qvi \times \frac{1013 + P}{1013}$$

Example:

Flow reading = 52.2 mc/h

Pressure at meter in mbar = 100

$$Qvc = 52.2 \times \frac{1013 + 100}{1013} = 57.35 \text{ m}^3/\text{h}$$

Use of this formula is advised when pressure at the meter is greater than 40 mbar.

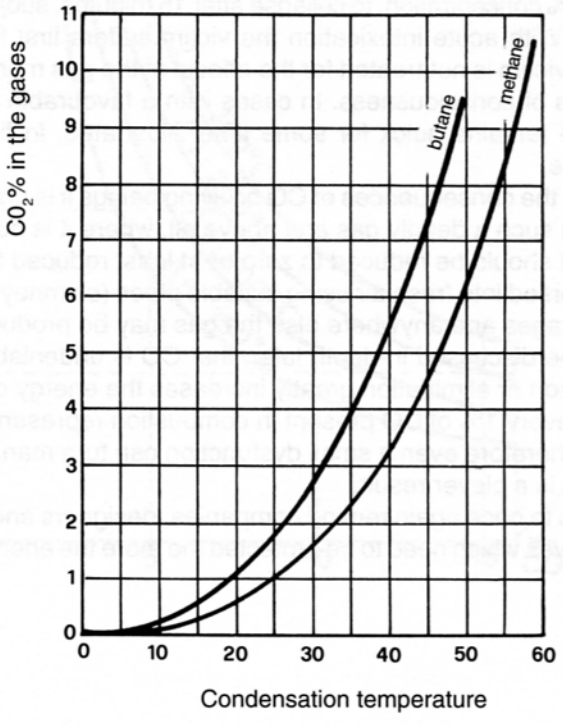
Enclosure "E"

Chimney Flues

Among the various problems which must be confronted in converting plants from liquid to gaseous fuel is the problem of the use of existing chimney flue.

Having been calulated for use with liquid fuels, the chimney flue sections are often too large for gas, thus causing the cooling of fumes to the condensation temperature of steam. As a cubic metre of methane gas produces considerable amounts of steam, it is easy to see the damage that could be caused. The water, as well as saturating the walls (an effect also visible from the outside), tends to slide down, dragging soot with it, which can cause dangerous obstructions.

- Increasing excess air, decreasing the CO_2 value; however, this solution leads to a decrease in output.
- Inserting liners of a suitable dimension inside the chimney flues and putting insulation between these and the walls of the chimney flue; this solution is definitely the best.
- Another "solution", a little empirical but efficient all the same, consists of introducing a secondary air source at the base of the chimney which, by diluting the CO_2 in the fumes, increases the temperature of the condensation. In this way the consensation of steam is avoided without affecting capacity (see Diagram 4).
- The chimney should not lose more than 1 degree / m



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CO, INVISIBLE ENEMY

Colourless, odorless, flavourless, carbon monoxide constitutes the most deceptive and dangerous product of all those that " burn"

Whether it is called carbon oxide, carbon monoxide or CO it remains what it is: a colourless, odorless, tasteless flammable gas (it burns with a pale blue flame); above all, having a density slightly lower than that of air it disperses in air forming explosive mixtures.
However it is not a difficult product to find, in fact it is produced wherever incomplete combustion of substances rich with carbon, due to lack of oxygen, takes place. Its measurement constitutes a method of control and regulation of combustion equipment. This gas forms in numerous situations; in high ovens in mines, in refineries and wherever something containing carbon is burnt. For this reason the professional risk, to employees working in an environment where products from the incomplete combustion of carbon are developed, could be very high; the risk can be equally high in a faulty "domestic" appliance with defective combustion, although the user is usually unaware of the risk.
Carbon monoxide is contained in gas and / or air in various percentages which are normally acceptable. Its percentage reaches 38% in water gas (town gas), varies from 0.3% to 15% in the exhaust fumes of petrol vehicles and 0.3% to 9% in diesel exhaust fumes, it is found in illuminating gas, the air in mines and also in car workshops (0.01% to 0.02%). Its harmful effects on the human organism are well known and unfortunately death due to carbon monoxide, voluntary and involuntary is not uncommon.
Incidentally, it has been observed that one of the side effects of the substitution of other gases by methane for domestic uses, is that it is practically impossible to commit suicide through inhalation. Inhaling water gas guaranteed the required result (suicide) due to the high concentration of CO however, inhaling methane will, at most, provoke bad stomach upsets due to the unpleasant smelling mercaptans used to add odor to the gas and rarely results in suicide. Carbon monoxide, when absorbed into the respiratory system, goes directly into the blood flow, carbon monoxide has an attraction for haemoglobin 300 times stronger than that of oxygen. The combining of carbon monoxide and haemoglobin forms carboxyhaemoglobin, it can no longer use or hold oxygen, in fact it is no longer adapted to the needs of animal life. Above all, this combination is so stable that it can only be split up by using large quantities of oxygen, It is evident that the extent of such formations is influenced by the percentage of carbon monoxide in the air breathed just as its elimination is influenced by its concentration in the blood. The physiological effects vary according to the percentage of CO in the air and the length of exposure and of course the amount of air inhaled, the consequences on the organism vary according to whether the subject is at rest (slow respiration) or exercising (frequent respiration).
The consequences range from a mild headache after 10 hours exposure with a concentration of 0.01% of CO in air to nausea and difficulty in breathing after 2 hours exposure when the subject is exercising in an atmosphere with a 0.02% concentration, to collapse after 15 minutes, subject at rest, with a concentration of 10000 ppm CO in air. With acute intoxication the victim suffers first from headaches, palpitations, vertigo and nausea, if the victim is not treated for the effects of the gas more serious effects are suffered: asthenia, drowsiness, loss of consciousness. In cases with a favourable result respiration is regulated gradually whilst the pulse remains quick for some time. Illustrated, in figure 1, are the physiological effects of carbon monoxide.
If the effects illustrated are the consequences of CO on living beings it is understandable that man should not come into contact with such a deadly gas and above all, where it is not a necessary component (as in the case of water gas) it should be reduced to zero or at least reduced to a minimum and if this is not possible it should be dispersed into fresh air using suitable pipes (chimneys or similar), this also goes for private heating plants, garages and anywhere else the gas may be produced.
We will just point out, to be discussed in-depth later, that CO is undeniably a precise indicator of poor combustion and its reduction or elimination greatly increases the energy of the fuels used.
Roughly we can say that every 1% of CO present in combustion represents a 5% decrease in output in a norrnal heat generator, therefore even a small dysfunction can turn management costs, of a plant, red which for a colourless gas is a clever result.
It would not be superfluous to once again remind companies, designers and installers that they must take care to safeguard human lives which need to be protected the more the enemy is deceptive and dangerous which CO is.

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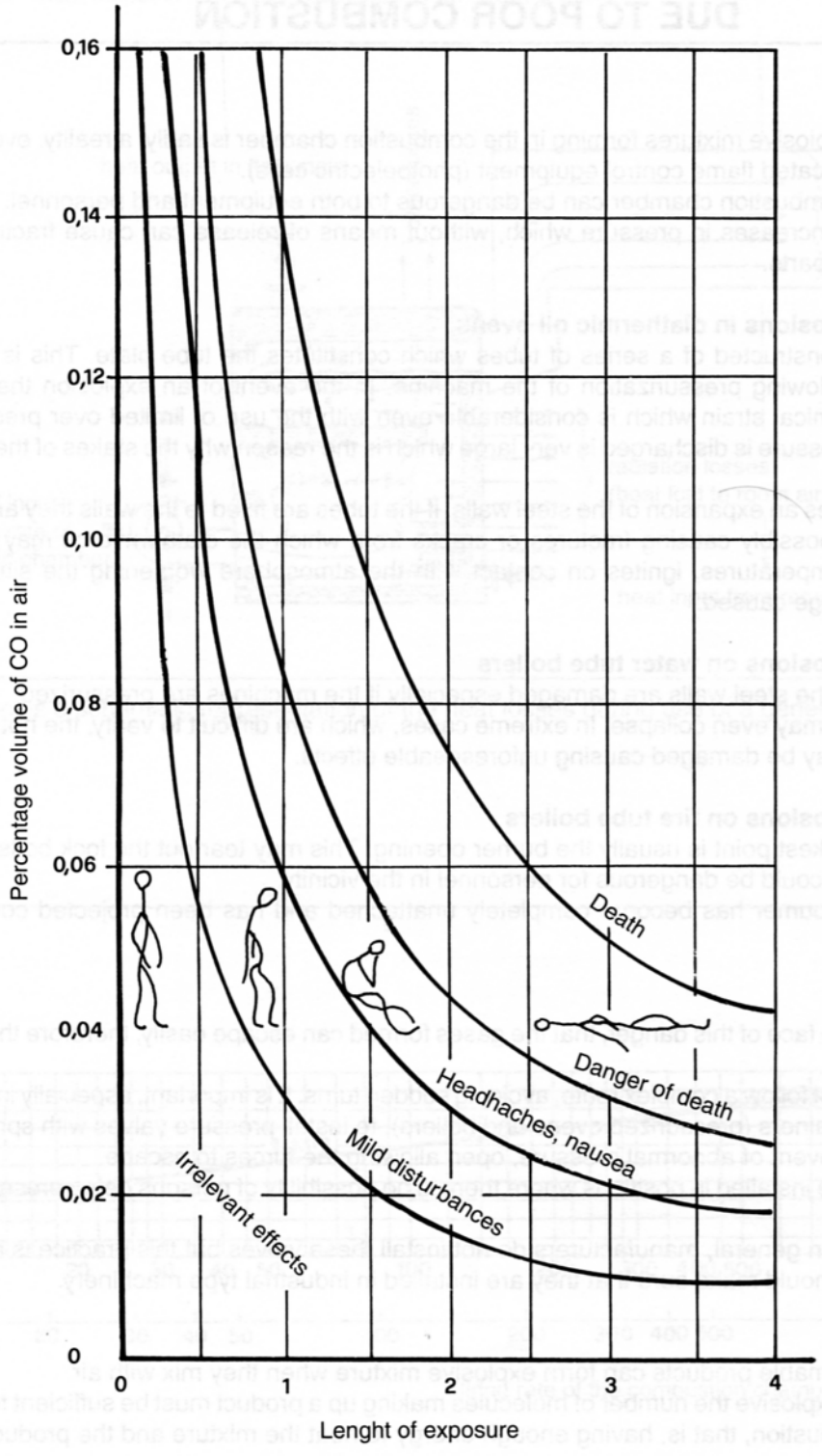

Fig. 5 The physiological effects of carbon monoxide

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DANGER OF EXPLOSIONS IN BOILERS DUE TO POOR COMBUSTION

The possibility of explosive mixtures forming in the combustion chamber is sadly, a reality, even with the presence of sophisticated flame control equipment (photoelectric cells).
Explosions in the combustion chamber can be dangerous to both equipment and personnel.
Explosions lead to increases in pressure which, without means of release can cause fractures in the structure's weakest parts.

The effects of explosions in diathermic oil ovens
These ovens are constructed of a series of tubes which constitutes the tube plate. This is contained within steel walls allowing pressurization of the machine. In the event of an explosion the walls are subjected to mechanical strain which is considerable even with the use of limited over pressure. The area in which the pressure is discharged is very large which is the reason why the stakes of the game are high.
Literally, this provokes an expansion of the steel walls, if the tubes are fixed to the walls they are dragged by the movement, possibly causing fractures or cracks from which the diathermic oil may leak. This leakage, at high temperatures, ignites on contact with the atmosphere worsening the situation and increasing the damage caused.

The effects of explosions on water tube boilers
In this case as well the steel walls are damaged especially if the machines are pressurized.
The refractory walls may even collapse. In extreme cases, which are difficult to verify, the hot water and vapour exit tubes may be damaged causing unforeseeable effects.

The effects of explosions on fire tube boilers
In this case the weakest point is usually the burner opening. This may tear out the lock bolts and open unexpectedly which could be dangerous for personnel in the vicinity.
In some cases the bumer has become completely unattached and has been projected considerable distances.

Passive protection
It is necessary, in the face of this danger, that the gases formed can escape easily, therefore the chimney is very important.
The chimney must not follow a complex route, avoiding sudden turns. It is important, especially in machines with large steel containers (pressurized ovens and boilers), to install pressure valves with spring closed doors which, in the event of abnormal pressure, open allowing the fumes to escape.
The valves should be installed in positions where there is no possibility of persons being present to avoid accidents.
For safety reasons, in general, manufacturers do not install these valves but this practice is not correct and the purchaser should make sure that they are installed in industrial type machinery.

Explosive mixture
The vapours of flammable products can forrn explosive mixture when they mix with air.
For a mixture to be explosive the number of molecules making up a product must be sufficient to maintain and propagate combustion, that is, having enough energy to heat the mixture and the products formed by combustion.
This is the lower inflammability limit, there is also the upper inflammability limit above which point the mixture is too rich to be able to self combust.
Between the two limits is the area in which inflammable and therefore explosive mixtures are formed.
It should be remembered that an explosion is no more than rapid combustion which produces large amounts of energy in a very short space of time. The exploding gases quickly increase in volume thus creating a destructive wave of pressure.
Table 5 shows the ignition temperature and upper and lower inflammability limits of various compounds.
By looking at the data relative to ignition temperatures, we can see that this is lower for liquid compounds than it is for gaseous compounds. This observation is important because it shows that even without a

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real primer liquids pouring over hot surfaces (diathermic oil ovens) can cause explosions.
It is also important to know the boiling point and inflammability temperature.
The lower temperature limit is linked to the tension of the vapour at which, in air, it reaches the lower inflammability limit. The higher temperature limit indicates the point above which the free vapour produces a mixture too rich to be inflammable.
Table 6 shows some of these values.

Tab. 5 - Ignition temperature and inflammability limit (National Fire Codes, U.S.A.).

Product	Ignition temperature	Inflammability limit °C on % air	
		Lower	Upper
Acetaldehyde	185	4,1	55
Ethyl acetate	426,7	2,5	9
Vinyl acetate	426,7	2,6	13,4
Acetone	537,8	2,6	12,8
Acetylene	299,4	2,5	81
Acetic acid	426,7	5,4	16
Hydrocyanic acid	537,8	6	41
Ethyl alcohol	422,8	4,3	19
Ammonia	651,1	16	25
Acetic anhydride	315,6	2,7	10
Benzole	562,2	1,4	7,1
Butane	405	1,9	8,5
Vinyl chloride	472,2	4	22
Cumene	423,9	-	-
Cyclo hexane	260	1,3	8
Ethylene	450	3,1	32
Formaldehyde	430	7	73
Heptane	223	1,2	6,7
Hexane	233,9	1,2	7,5
Hydrogen	585	4	75
Hydrogen sulphide	260	4,3	45
Isobutane	462,2	1,8	8,4
Kersosene	228,9	0,7	5
Methane	537,2	5,3	14
Propane	466,1	2,2	9,5
Propylene	410	2,4	10,3
Styrene	490	1,1	6,1
Carbon disulphide	100	1,3	44
Toluol	536,1	1,4	6,7
Xylene	463,9	1	6
Benzene	280	1,4	7,6
Ethane	515	3	12,5
Petroleum ether	287,8	1,1	5,9
Naphthalene	526,1	0,9	5,9
Nonane	206,1	0,8	2,9
Octane	220	1	-
Pentane	308,9	1,5	7,8

Tab. 6 - Boiling point and inflammability temperature.

Compound	Boiling point	Inflammability temperature	
		Lower limit	Upper limit
Acetic acid	118,1	37,3	57,9
Acetone	56,5	-20	5
Methyl alcohol	66	8	37
Nafta	Variable	37	73
Glycol propylene	188	96	130

Formation of explosive mixtures in the furnace

Above all, it is necessary to identify the type of combustible, liquid or gaseous.
When using gaseous fuels it is important to prevent incombustible gases from entering into the valve system. It is advisable to have two command valves, one for the pilot burner and one for the principal bumer and between these two, another valve which is left open with a vent leading outside the boiler. Thus any leakage from the first valve is sent out instead of entering the boiler.
Before start up the combustion chamber must be ventilated, which acts as a clean out phase, this process is fairly easy because the gas is easily cleaned out by the air current, however this is not the case with liquid fuels, any incombustible fuel that has entered is not easily cleaned out by simple ventilation. The liquid continues to evaporate, forming mixtures of gas which can ignite at fairly low temperatures, about 200°C.
Unfortunately heavy oil may enter even when a photocell, which displays the presence of a flame, is installed. In the event of poor pulverization or low pressure or abnormal turbulence of the air/fuel mixture, the drops of heavy oil may reach the walls incompletely burnt and then drip down into the boiler.
This phenomenon can carry on for some time as the photocell continues to show the presence of a flame and therefore will not interrupt the burner work cycle.
In these case the danger becomes difficult to control because small flames may form which consume oxygen simultaneously changing the relationship between vapour and oxygen and possibly allowing the mixture to enter between the explosive limits, even when the burner is shut down.
It is obvious that a phenomenon of this type is difficult to control and it should be avoided at all costs by carrying out frequent controls and analysing the fumes in the combustion chamber.
In a practical case, that happened to me, damage was avoided when large amounts of fuel entered, causing the burner to shut down but without turning the fan motor off with the damper completely open. There were small and localized explosions which were ventilated by the chimney. The heavy oil, which had entered, was then cleaned out mechanically and the rest was then burnt by running the burner at minimum and stopping it frequently.
To avoid excess pressure the inspection doors were left open to help ventilate the gas. The operation lasted for a couple of hours and was concluded successfully in spite of the minor explosions.

Safety of combustion plant

As we have already said, it is necessary to ensure that no incompletely burnt fuel enters the combustion chamber. Thus it is important that leakage control equipment is maintained properly and is in perfect working order. Before starting up a boiler it is very important to carry out a thorough ventilation to expel any incombustible gases. For the ventilation to be effective it must be changed at least 6 to 8 times the total volume of the machine and the fan motor damper must be completely open to eliminate any possible pockets of gas in remote corners. Once the ventilation has been carried out you can proceed with start up using the pilot burner fuelled by methane or liquid gas, mixed correctly with air.
Correct start up takes place by a spark between the two electrodes near the mixture to be burnt. In some modern burners the principal fuel flow is lit directly by the electrodes.
In both cases it is extremely important that the flame display system, constituted of a photo probe, is in perfect working order so that if is does not show the presence of a flame or displays abnormalities the burner will be arrested immediately by means of a relay closing the fuel intake valves. Remembering that when a burner arrests it is advisable to have an operator inspect the machine, including automatic machines, in order to ascertain the real cause of the problem.
At this point it is necessary to control the fuel circuit and check that both the electrodes and the photo probe are perfectly clean. Naturally after the burner has been arrested it is necessary to begin start up procedures from zero making sure that the cleaning phase is thorough.
It is important to be sure that the photo cell works properly and will only display the presence of a flame and not, for example, the radiation of incandescent refractory material. The most modern photo celles can only pick up the radiation of the flame emitted in the UV field and therefore are very efficient.
As we have already said it is not enough that the photo cell displays the flame presence but it is also necessary that supply of combustion air and fuel are correct. For example, it is important that the combustion fan motor works perfectly, this is controlled with the use of a pressure gauge which arrests the burner when the air pressure is incorrect.
Proceed similarly for the fuel, which must comply with the normal limits of the burners work cycle. It is advisable to control the calibration of the relationship between fuel and air at regular intervals and carry out calibration immediately when there are incombustibles or large excesses of air present.
With oil fuel ovens it is recommended to measure the pressure in the combustion chamber, if the pressure is too high, which signals micro explosions, the fuel flow must be interrupted immediately without stopping

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the fan motor so that the gases present are expelled. After such an intervention it is advisable to open the boiler to ensure no unburnt heavy oil has entered. If the oil has entered it is necessary to carry out a thorough cleaning, mechanically expelling the oil that has entered. The last traces can be burnt, proceeding cautiously as described above.

Ignition programmer
Modern burners are equipped with a special "sequence programmer" which guarantees correct execution of the ignition phase, to this one can add the other measures mentioned above.

Unburnt substance detector
There are special devices on the market which are able to detect the presence of unburnt substances. They take an air sample to analyse from the combustion chamber and if there is any danger they prevent start up of automatic machines or, in the case of manual machines, indicate the danger to the operator.

EXPLOSION CAUSED BY FORCED DRAUGHT GAS BURNER

a) Component involved: Modulating forced draught gas burner installed in a vapour generator.
b) Precedents: During maximum vapour production the burner tended to switch itself off thus examination by a burner expert was necessary.
c) Event: Explosion in the combustion chamber
d) Details of incident: Due to the problem described above, for which the burner expert was called. He detected that as the request for vapour slowly increased the flame turned reddish due to lack of air causing the damper to open manually. There was an explosion which filled the posterior chamber with fumes and tore the doors of the anterior chamber.
e) Consequences: The torn off anterior door hit and killed the operator, the stoker was hit by the flame and badly burnt. The water treatment plant was destroyed by the posterior door of the generator, there was no damage to the internal structure of the generator.
f) Cause: The trouble which occurred in the course of the work cycle was caused by an intake of combustion air which was inadequate for the increase in gas flow (increase controlled by a pressure gauge in correlation with the increases in vapour withdrawn). Unburnt substances in the form of carbon monoxide and unburnt gas formed at the bottom of the flame, which in the absence of air, were dispersed in the chimney without problems. The unexpected opening of the damper supplied the air necessary to form the explosive mixture and the presence of the flame provided the necessary primer.
g) Prevention:
   1) It is necessary to assure, with modulating gas burners, that an adequate increase in air accompanies an increase in gas. Such conditions should be controlled periodically.
   2) When using generators of the type in question it is necessary to install at least two protection devices which work on independant circuits to prevent the flow of combustion air falling below the level necessary for complete combustion.
   3) It must be made clear to the operator a that there is a danger of explosion in the presence of a flame (the majority are convinced that the danger only exists when the flame goes out).

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CONTROL OF COMBUSTION

Thermal Output

The term "output," when refering to a machine, is the relationship between the desired effect and the force used or the input needed for it to work. For example, in reference to a heat generator, boiler plus burner, the desired effect is the heating of the water, that is, the transfer of a certain amount of heat to the water circulating in the boiler, this is called *useful heat.* The input is the consumption of fuel, that is, the heat supplied to the furnace by burning a certain amount of fuel, this is called *spent heat.*

Therefore the thermal output "η" of a heat generator is defined as follows:

$$\text{Thermal output } (\eta) = \frac{\text{usefulheat}}{\text{spent heat}}$$

In theory it would seem that all the heat produced in the furnace by burning the fuel should be absorbed by the water and in that case the thermal output would equal 1. However in reality this is not true, the thermal output is always less than 1 because the generator is subject to losses of heat, ie heat that is lost during the work cycle.*

Even if it is well insulated heat does escape from the high temperatures of the combustion chamber to the much lower temperatures outside, in the boiler, aswell as this the products of combustion, that is, the fumes, are expelled through the chimney, their expulsion or movement is easier the hotter they are in comparison to the outside air. In this way the hot fumes are expelled and disperse a certain amount of heat outside, which is not absorbed by the water in the boiler.

It can happen that the fuel is not completely burnt, either due to a poor mixture with the combustion air and therefore lack of oxygen or due to cold zones in the combustion chamber or other causes. In such a case, there will be *unburnt solids,* in practice particles of unburnt carbon, and *unburnt gases,* mainly carbon monoxide, present in the fumes. This means that combustion does not produce the maximum heat possible, equal to the inferior heat capacity of the fuel and the inferior output can be considered as another loss of heat.

For obvious economic reasons the effect of lost heat must be contained as much as possible, the thermal output for newly constructed generators is around 85 - 90%, 70 - 85% for older generators and for some even less. The values vary according to the capacity of the generators, the lower the capacity the lower the value.**

---

* If in a generator the heat actually transfered to the water, use*ful heat,* equals 50000 kcal/h (58.15 kW) and the heat spent, that is, the fuel burnt is 60000 kcal/h (68.78kW) output is:

$$\eta = \frac{\text{useful heat}}{\text{spent heat}} = \frac{50000 \text{ kcal/h}}{60000 \text{ kcal/h}} = 83.3\%$$

Lost heat, equal to spent heat minus useful heat, equals 60000 kcal/h (68.78 kW) - 50000 kcal/h (58.15kW) = 10000 kcal/h (10.63 kW) and is equal to 16.7% of the heat spent:

$$\frac{\text{Lostheat}}{\text{spent heat}} = \frac{10000 \text{ kcal/h}}{60000 \text{ kcal/h}} = 0.167 = \frac{\text{spentheat - usefulheat}}{\text{spent heat}} = 1-\eta$$

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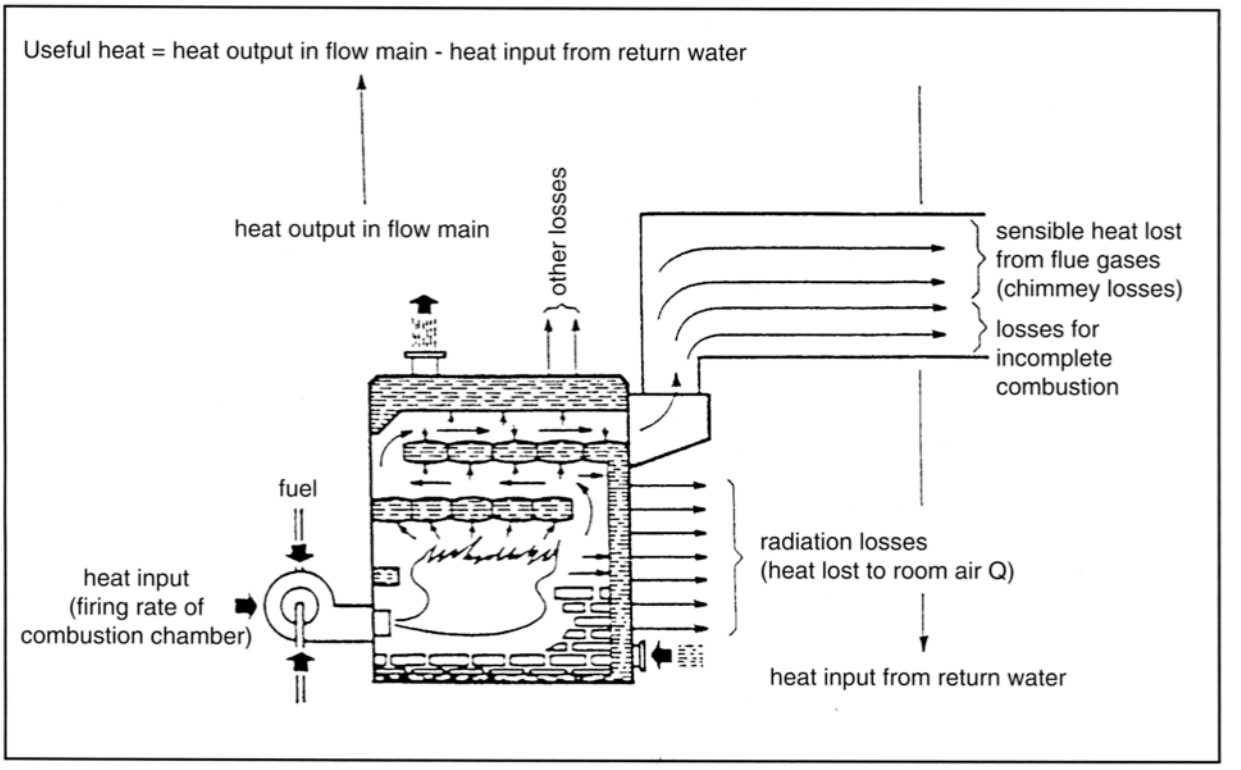
Useful heat = heat output in flow main - heat input from return water
heat output in flow main
other losses
sensible heat lost from flue gases (chimmey losses)
losses for incomplete combustion
fuel
heat input (firing rate of combustion chamber)
radiation losses (heat lost to room air Q)
heat input from return water

Fig. 6.1 shows a schematic representation of the heat losses during use of a generator.

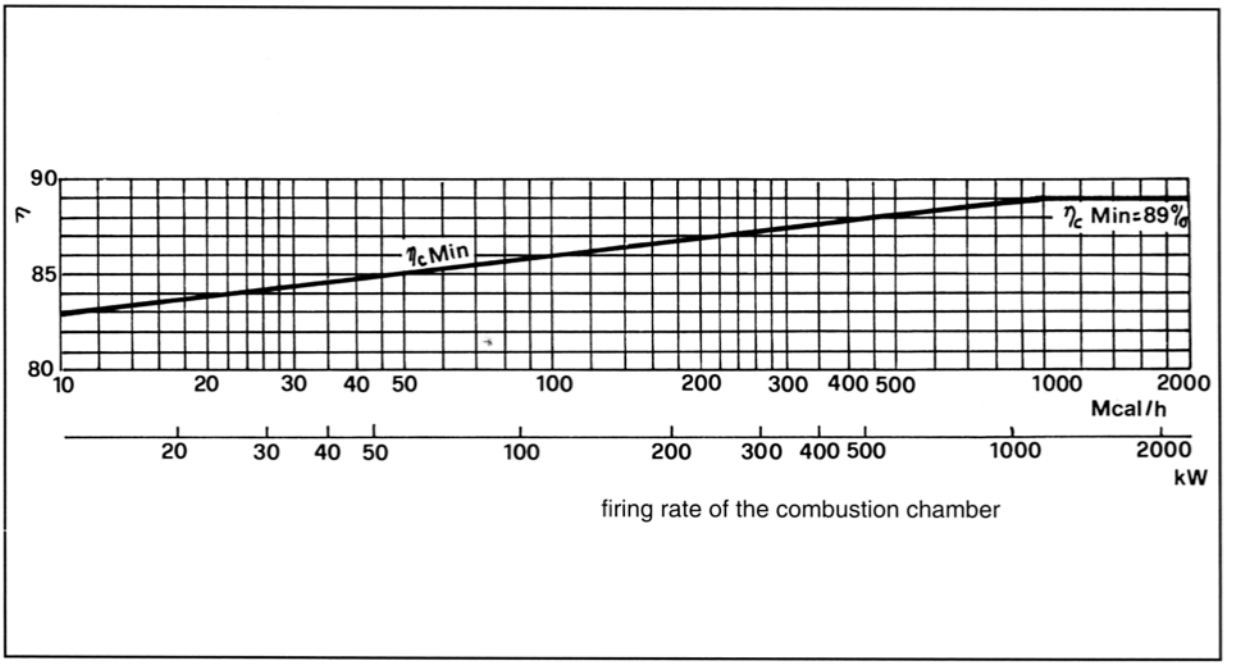

Fig. 6.2 Shows the min. acceptable flue gase losses for heat generators

Heat losses

In this paragraph elements are supplied with which to evaluate the different types of heat losses which take place during the work cycle of a generator.

NOTICEABLE HEAT LOSSES P_s

This is the heat lost with the fumes in the chimney due to their temperature. In fact they are called noticeable heat because it can be felt by the senses. This loss depends on the amount and temperature of fumes produced, that is the loss is larger the larger the quantity and higher the temperature of the fumes produced during combustion. The quantity of fumes produced depends,not only on the amount of fuel, but also on the amount of excess air used in combustion, that is the larger the amount of excess air the larger the amount of fumes produced. In a certain quantity the excess air is dispersed in the chimney with the fumes, at which point its temperature is higher than when it entered (environment temperature). The operator should ensure that there is only the minimum of excess air required to prevent the formation of unburnt substances, that is the quantity of excess air compatible with the needs of the plant. Table 7 shows average indicative values expressed as % which are valid for plant in good working order. As far as the temperature of the fumes is concerned, the other characteristics that effects the increase in noticeable heat losses, it is necessary to note that it cannot be reduced below a certain point, for example, below the condensation temperature of acid to avoid corrosion. The temperature of the fumes must be high enough to ensure that all the fumes are expelled, it must not be lower than the limits fixed by standards.

	Air excess %	Air excess coefficients	CO2 %	O2 %
Heavy oil	30	1,3	11,8	5
Light oil	25	1,25	12	4,3
Methane	20	1,2	10	3
Coke	50	1,5	13,5	7,4

Table 7

The temperature of combustion products is influenced by the cleanliness of the exchange surfaces, if these surfaces are dirty, the temperature of the fumes will be higher than normal.
Noticeable heat losses through the chimney are usually, in respect to the other losses, predominant but are those that are most easily reduced with good planning and careful setting of the generator.
The calculation of noticeable heat losses is worked out using the following formula (Hassenstein):

$$P_s = K_s \frac{t_f - t_a}{CO_2}$$

where

P_s = the value of noticeable heat lost expressed as a percentage
t_f = the temperature of fumes in °C
t_a = the temperature of combustion air in °C
$C0_2$ = the percentage volume of carbon dioxide in dry fumes
K_s = 0 495 + 0.00693 x CO_2 for light oil
K_s = 0.516 + 0.00670 x CO_2 for fuel oil
K_s = 0 379 + 0.00970 x CO_2 for natural gas
K_s = 0.67 for coke

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For a more immediate evaluation of noticeable heat loss, Figs. 6.3, 6.4 and 6.5 show the losses in relation to the percentage volume of CO_2 in dry fumes and the temperature of the fumes. Finally it is important to point out that in the case of incomplete combustion (presence of carbon monoxide) Hassenstein's formula is no longer correct and the resulting value will show an error of excess. In the case of incomplete combustion more precise methods of calculation, which are shown in the specialized technical literature, must be used.

NUMERICAL APPLICATION

Calculate the noticeable losses in the combustion of light oil in the following conditions:

CO_2 13%
tf 230°C
ta 20°C

In relation to a percentage volume of CO_2 of 13.5% we obtain the following values for light oil from the Hassenstein constant:

$$K_S = 0.495 + 0.00693 \times 13 = 0.585$$

Therefore the noticeable heat losses =

$$Ps = 0.585 \times \frac{230-20}{13} = 9.45\%$$

From Fig. 6.4 we obtain a value of about 9 when $\Delta t = 230 - 20 = 210$ and $CO_2 = 13$.

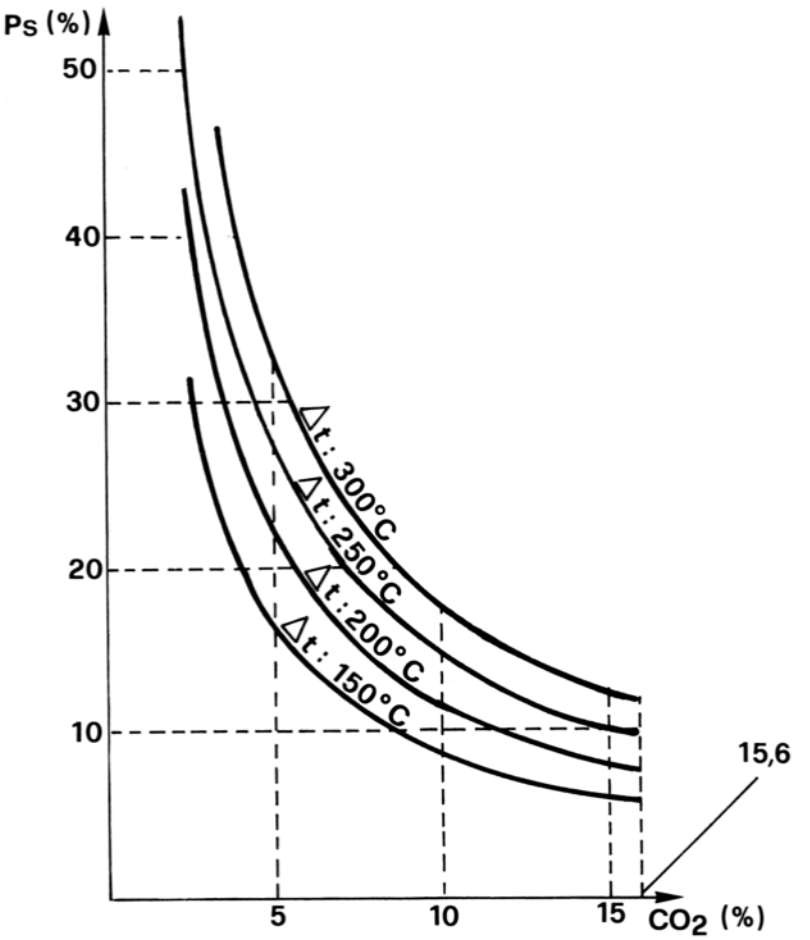

Fig. 6.3

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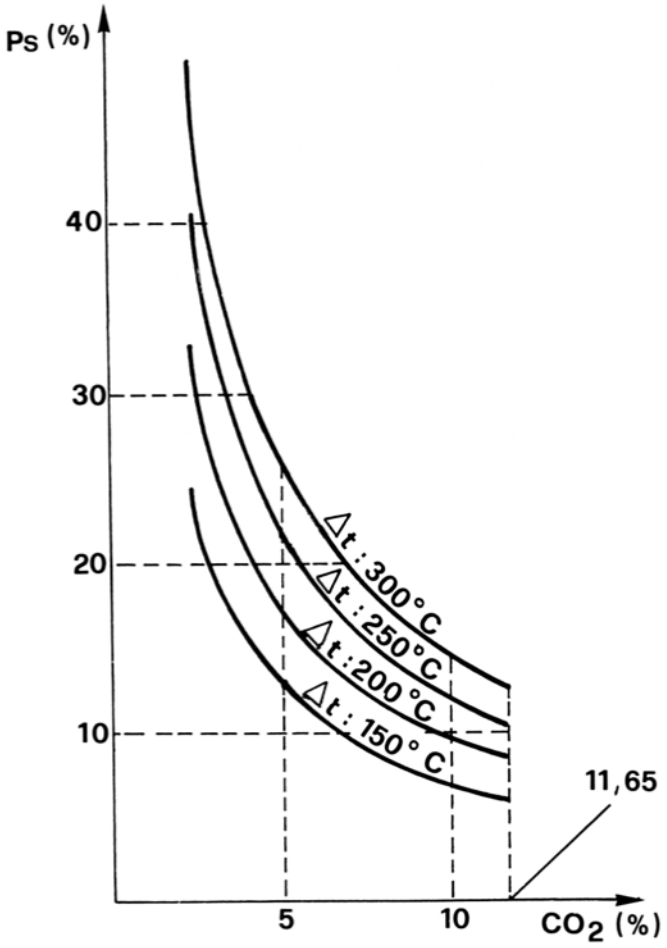

Fig. 6.4

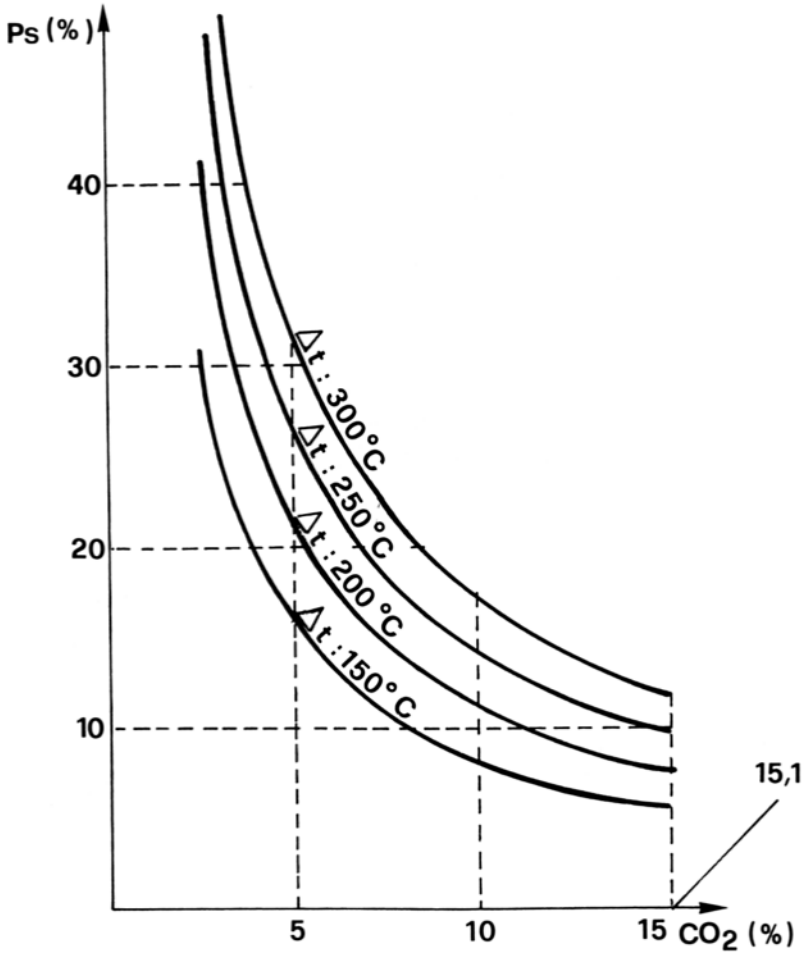

Fig. 6.5

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LOSSES FOR INCOMPLETE COMBUSTION, Pc

These losses occur due to the formation of unburnt solids* or gases (soot, carbon monoxide and rarely hydrogen) which prevent the development of the fuels total heat potential. These unburnt substances are formed from the fuel and are disposed of through the chimney without supplying all the heat of which they would be capable if burnt completely.
Such losses usually occur in the combustion of piece coal, for all other fuels they can be reduced noticeably and brought down to an insignificant level with normal combustion control.
Incomplete combustion losses can be measured to determine the percentage volume of carbon monoxide present in the fumes. If the concentrations of CO (carbon monoxide) and CO_2 (carbon dioxide) are known it is possible to calculate the losses due to incomplete combustion, using the following formula:

$$P_c = K_c \frac{CO}{CO_2 + CO}$$

in which CO and CO_2 represent, respectively, the percentage volumes of carbon monoxide and carbon dioxide measured in the fumes. Pc are percentage losses due to incomplete combustion.

K_c is a constant which depends on the fuel used, its maximum values are as follows:

K_c = 50-5 for oil fuel
K_c = 59 for coal
K_c = 37-9 for methane

The presence of carbon monoxide (CO) in the flue gases represents a large heat loss, for every 1% of CO present output is reduced by 5%. For this reason standards, relative to the consumption of fuel for the heating of buildings, limits the percentage volume of carbon monoxide in flue gases to a maximum of 0.1%.**

NUMERICAL APPLICATION

Example: Using methane Kc = 37.9, analysis of flue gases reveals the following:

CO_2 = 9%
CO = 0.1%

The losses for incomplete combustion =

$$P_c = 37.9 \times \frac{0.1}{9 + 0.1} = 0.42\%$$

Being a very toxic gas, the maximum percentage volume of CO that can be emitted (equal to 0.1 %) has been set at such a level that after normal dilution due to air exchange, its concentration in the atmosphere is not considered dangerous.

---

* Unburnt solids can be separated into:
- soot particles with diameter of 0.01 to 0.5 micrometres
- particles produced by cracking of small drops of liquid fuel with diameter of 1 to 100 micrometers.

RADIATION LOSSES P_i

These so called losses are due to the inevitable thermal exchange between the generator and the atmosphere. In fact even if the generator is well insulated it always loses a certain amount of heat into the atmosphere.
The transmission of heat simultaneously takes place by the three classic methods of propagation, that is, conduction, convection and radiation. For the sake of simplicity we talk of radiation losses when we are refering to all losses caused by the thermal exchange between generator and atmosphere.
Theoretically speaking, an analytical calculation of such losses is not difficult, in fact there are methods, instrumentation and formulas to calculate the three methods of heat propagation (conduction, convection and radiation) which can be used in relation to the temperature and surface of the walls and the temperature and speed of the air outside etc.
However in reality many of these parameters mentioned above are of uncertain definition and therefore the results obtained using these analytical methods are no more accurate than those obtained from tables and diagrams based on experimental data for type and capacity of generator.
Fig 6.6 shows a diagram from which it is possible to obtain the percentage value of radiation losses in relation to furnace capacity of a generator working at maximum.
Radiation losses, as a percentage of heat spent, increase as power decreases, for all generator types. In fact radiation losses almost equal an absolute value whether the generator is running at maximum or much less than maximum.

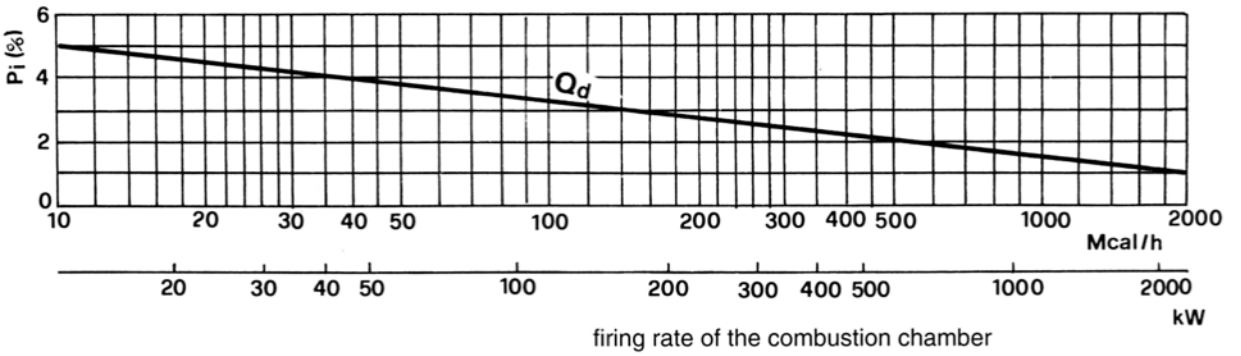

Fig. 6.6 Loss Pi as percentage of thermal capacity of furnace in generator running at maximum.

Thus the percentage of heat lost is higher when the generator is working at low capacity in relation to the percentage loss at maximum capacity.
The following Fig. 6.7 displays these ideas more comprehensibly.
As is clearly visible, a generator with a radiation loss of 4% at maximum capacity has a loss of about 8% when running at half capacity.

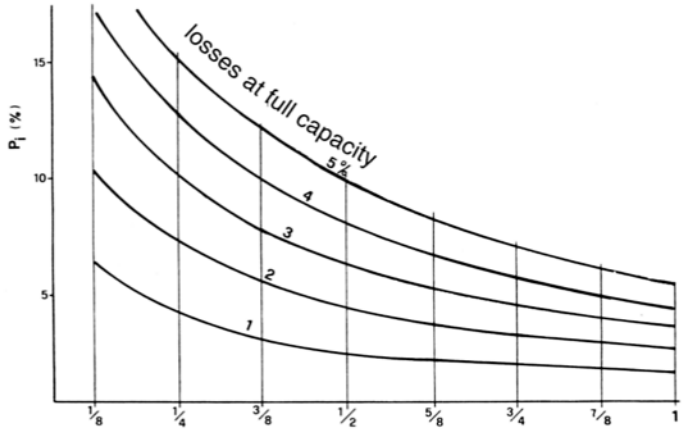

Fig. 6.7 Radiation loss at reduced capacity in relation to capacity used for several values of loss at maximum capacity.

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VARIOUS LOSSES, P_V

These are the losses that can be allocated to various causes, heat lost during cleaning, heat sensitive to solid residues etc. Their difference can be evaluated by expressing the losses as percentages of spent heat (furnace capacity).

$P_V = 100 - \eta - P_S - P_C - P_i$

NUMERICAL APPLICATION

Output	$\eta = 87.0\ \%$
Noticeable heat losses	$P_S = 9.18\%$
Losses due to incomplete combustion	$P_C = 0.42\%$
Radiation losses	$P_i = 2.0\%$
Various losses (100 -87 - 9.18 - 0.42 - 2 = 1.4)	$P_V = 1.4\%$

THERMAL BALANCE

The thermal balance expresses the numerical calculation of the heat or energies that enter and exit a heat generator and confirms that, under regime conditions, thermal energy entering the system equals that exiting. The term thermal energy includes chemical energy and any other forms that transform into thermal energy.*

With reference to the schematic representation (Fig. 6.1), application of the thermal balance to a heat generator results in the following expression in which the generator is assumed to be in regime, that is temperature, pressure, heat and water level in the generator are assumed to remain constant over time:

$Q_c = Q_u + Q_f + Q_d$

The above expression means that the quantity of heat produced by combustion, spent heat (Q_c), must be equal to useful heat (Q_u), heat lost to the water plus lost heat ($Q_f + Q_d$), that is heat lost to the chimney plus heat lost to the atmosphere through the generator walls. Evaluating the quantity of heat at time intervals, hours or seconds, the result is the expression of the balance in terrns of thermal capacity:

$q_c = q_u + q_f + q_d$

where the symbols have the following meanings: q_c = thermal capacity produced by combustion or fumace capacity:

$qc = Hi \times \Gamma_c$

where Hi equals the inferior heat capacity and Γ_c is the mass flow or consumption of fuel in the time period;

q_u = useful thermal capacity (capacity exiting with hot water produced - capacity re-entering with water):

$q_u = c_a \times \Gamma_a \times (t_u - t_a)$

where c_a equals specific (mass) heat of water (average value), Γ_a is the mass flow of water in circulation in the boiler, t_u is the exit temperature of the hot water and t_e is the temperature of the water re-entering;

* This, in practice, is the application of the principal of heat conservation from heat generators

q_f = thermal capacity lost to fumes due to noticeable heat:

$$q_f = c_f \times \Gamma_c \times v_f (t_f - t_a)$$

c_f equals specific heat (volume) of fumes, Γ_c equals mass flow or consumption of fuel, v_f equals volume of fumes produced for every kilogram of fuel burnt, t_f is the temperature of exiting fumes and t_a, the temperature of the atmosphere.

q_d = thermal capacity dispersed in thr atmosphere due to convection, conduction and radiation, which can be evaluated using the diagram in the previous paragraph.

By dividing the equation which expresses the thermal balance in terms of quantity of heat (or thermal capacity) by the heat (or capacity) produced in the fumace by burning the fuel q_c and multiplying by 100 we get the relationship between ouput and losses:

$$\frac{q_u}{q_c} \times 100 + \frac{q_f}{q_c} \times 100 + \frac{q_d}{q_c} \times 100 = \frac{q_c}{q_c} \times 100$$

$$\eta + P_s + P_i + P_v = 100$$

where $\frac{q_u}{q_c} \times 100\ \eta$ is the value of useful thermal output

$$\frac{q_u + q_d}{q_c} \times 100 = \frac{q_c - q_f}{q_c} \times 100 = \eta_c$$

is the value of conventional thermal output or combustion output

$\frac{q_f}{q_c} \times 100 = P_s$ is the percentage value of noticeable losses lost to the fumes in the chimney

$\frac{q_d}{q_c} \times 100 = P_i + P_v$ is the sum of the percentage values of the losses due to convection, conduction andradiation.*

In summary, the term *thermal balance* means the global evaluation of heat spent, both that used and that lost, according to the previous definitions. The balance can be carried out:

- in an *indirect manner* measuring heat spent, heat lost at the chimney, evaluating, with the use of suitable diagrams or correlations, the other losses of heat and then calculating the difference which is the heat used. The result from this method is the evaluation of combustion output η_c.
- in a *direct manner,* measuring the heat spent, heat used, heat lost in the chimney (noticeable losses and unburnt substances) and then working out the difference which equals heat lost through convection, radiation, conduction and other causes. In this case the result is an evaluation of useful output η.

NUMERICAL APPLICATION

Thermal output of a generator can be calculated directly or indirectly.

Known Data

Temperature of fumes	t_f = 230°C
Temperature of water leaving generator	t_u = 90°C
Temperature of water entering generator	t_e = 60°C

* Losses due to incomplete combustion are not considered as they are negligible

Temperature of combustion air (atmospheric air)	t_a = 20°C
Flow of water	Γ_a = 2000kg/h (0.556 kg/s)
Flow of fuel (consumption)	Γc = 7.2kg/h (0.002 kg/s)
Inferior heat capacity of fuel oil	H_i = 9700kcal/kg (40.6 MJ/kg)
Volume of carbon dioxide in fumes	13%
Volume of carbon monoxide in fumes	Negligible

Execution of calculations

- Indirect method

Thermal capacity of fumace (heat spent)

$q_c = \Gamma_c \times H_i = 7.2 \times 9700 = 68840$ kcal/h (80kW)

Thermal capacity lost in chimney (noticeable heat loss)*

$$q_f = P_s \times \frac{90}{100} = K_s \times \frac{t_f - t_a}{CO} \times \frac{q_c}{100} = 0.603 \times \frac{230 - 20}{13} \times \frac{68840}{100} = 6707\text{kcal/h (7.8 kW)}$$

Thermal capacity exchanged with atmosphere (radiation heat loss):**

$$q_d = P_i \times \frac{q_c}{100} = 3.6 \times \frac{68840}{100} = 2478 \text{ kcal/h (2.88 kW)}$$

Useful thermal capacity (useful heat, equal to heat spent minus heat lost, this value is obtained from the following relation):

$q_u = q_c - (q_f - q_d) = 68840 - (6707 - 2478) = 59655$

Conventional thermal output or combustion output:

$$\eta c = \frac{q_u + q_d}{qc} \times 100 = \frac{qc - qf}{qc} \times 100 = \frac{68840 - 6707}{68840} \times 100 = 90.3\ \%$$

Useful thermal output:

$$\eta = \frac{q_u}{qc} \times 100 = \frac{58655}{68840} = 86.7\%$$

-Direct method

Unlike the indirect method, the direet method uses direet determination of the useful thermal eapaeity, that is the thermal capacity lost in water, using the following expression:

$q_u = c_a \times \Gamma a \times (t_u \times t_e) = 1.0007^{***} \times 2000 \times (90 \times 60)$

Thus we can calculate immediately the useful thermal output:

---

* $K_s = 0.516+0.0067 \times CO_2 = 0.516+0.087 = 0.603$

** The value for P_i is taken from Fig. 6.6 corresponding to the value q_c = 80kW: P_i = 3.6%

*** The specific heat of water, ca, varies with the temperature, 1.0007 is the value which corresponds to 75°C - average value between water entering boiler at 60°C and leaving at 90°C.

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$$\eta = \frac{q_u}{qc} \times 100 = \frac{60042}{68840} = 87.2\%$$

Theoretically the value of useful output obtained using the direct method is more reliable than that obtained using the indirect method, however sometimes it is more approximate due to the possibility of error in measurement of flow and temperature of the water. For this reason the direct method is used to achieve very accurate results, carried out in laboratories where there is adequately precise measurement equipment.

Analysis of the products of combustion

As well as verifying that the level of carbon monoxide (CO) in the fumes does not exceed the limit set by standards,* to be able to evaluate the losses due to noticeable heat losses and incomplete combustion it is necessary to carry out a chemical analysis of the combustion products and measurement of the temperature of the fumes leaving the generator.**

The fumes generally produced in complete combustion with excess air are made up of carbon, dioxide, water vapour, nitrogen, oxygen, sulphur dioxide and traces of soot (unburnt solids).

The fumes which no longer contain water are called "anhydrides" to distinguish them from fumes in which the water vapour has not yet condensed, these are called "humids." In practice, the analysis, with equipment used for examining the products of combustion, is carried on cooled and therefore "anhydride" fumes, as a consequence the vanous formulas used refer to the analysis of anhydrous fumes, that is fumes with no water content.

Using fairly simple methods and equipment, which will be described later, the percentage volumes of CO_2 and O_2 can be determined, SO_2 is included with CO_2 and thus is disregarded. The percentage volume of nitrogen is calculated as the difference to 100, that is:

$$N_2 = 100 - CO_2 - O_2$$

In the case of incomplete combustion (due, for example, to lack of air) CO (carbon monoxide) may be formed therefore it is also necessary to calculate the percentage volume of CO. By knowing the chemical composition of a fuel it is possible to calculate the percentage volumes in air of the various combustion products when varying the level of excess air. With these values, which refer to dry fumes, it is possible to construct diagrams, which allow us to calculate the level of excess air from the percentage volume of carbon dioxide and oxygen in the fumes.

* The level of CO in fumes must not, in any case, exceed 0.1% of the volume of dry fumes without air.
** The temperature of fumes emitted from thermal plant, measured at exit, must be higher than 90°C except in start up periods".

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OSTWALD DIAGRAM

This diagram, which is different for each fuel, allows us to see whether combustion is complete from the percentage volumes of CO and O_2 in anhydrous fumes, if combustion is incomplete we can also calculate the percentage volumes of unburnt substances present. It is also possible to obtain, directly, the level of excess air thereby controlling that the analysis is correct. Figs. 6.8, 6.9 and 6.10 show the Ostwald triangles for light oil, fuel oil and methane. The diagram is in the form of a right angled triangle, the vertical axis represents the percentage volume of O_2 in anhydrous fumes up to a maximum of 20.8% which is equal to the percentage volume of oxygen in air. The horizontal axis represents the percentage volume of CO_2 up to a maximum which corresponds with the level at complete combustion in theoretical air (CO_2 max.). The hypotenuse gives the co-ordinator of the values corresponding to complete combustion. The triangle is completed with the lines which correspond to incomplete combustion, with increasing percentages of CO, which are found inside the triangle, parallel to the hypotenuse, and the excess air lines, both for complete and incomplete combustion.

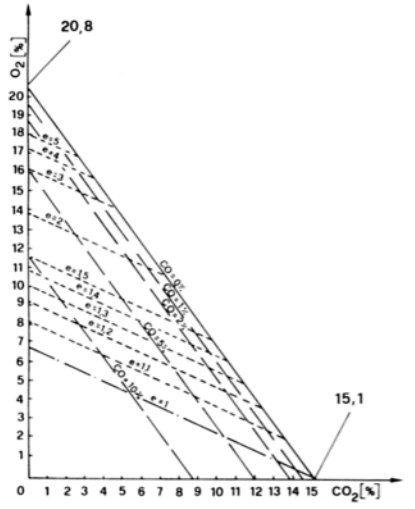

Fig. 6.8 - Ostwald triangle for light oil

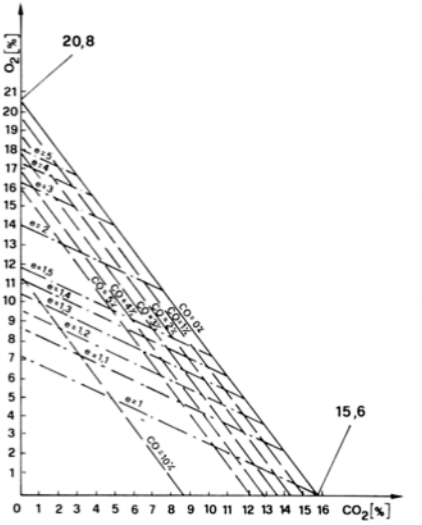

Fig. 6.9 - Ostwald triangle for heavy fuel oil 3-5° E

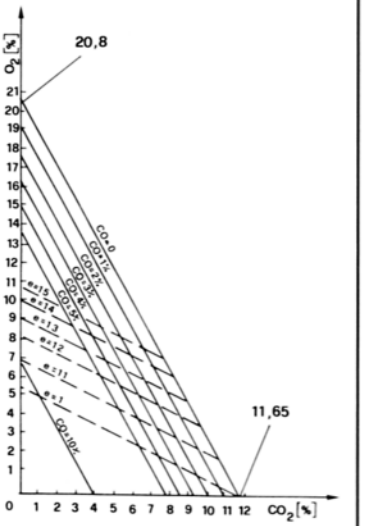

Fig. 6.10 - Ostwald triangle for methane

ANALYSIS OF COMBUSTION PRODUCTS

The percentage composition of combustion products can be calculated using physical or chemical methods.

Analysis of combustion products by chemical method

Excluding water vapour and disregarding impurities, the fumes are composed mainly of carbon dioxide (CO_2), sulphur dioxide (SO_2), nitrogen (N_2), oxygen (O_2) and possibly carbon monoxide (CO).
Using the chemical method, the percentage volume of the mixture $CO_2 + SO_2 + O_2$ is worked out, where present CO can also be calculated, whilst nitrogen is worked out by difference.
($N_2 = 100 - CO_2 - SO_2 - O_2$)
The ORSAT apparatus is the instrument most commonly used for the analysis.This is comprised of a sample and measurement system and three absorption laboratories, as shown in Fig. 6.11b.
A graduated burette (N° 1 in Fig.) with a capacity of 100 cm^3 (a smaller volume burette can be used as the scale is graduated in hundredths, to be precise each unit must correspond to a hundredth of the volume of the burette.) is attached to a system which allows the inspiration and expiration of the gases to be analyzed, usually this involves the use of a hydraulic system which uses the communicating vessel principle.
The burette is connected, by a flexible tube, to a moveable bottle containing water (N° 2 in Fig.).
Lifting the bottle, the water passes into the burette and pushes the fumes out (and vice versa, lowering the bottle draws the fumes back).
The three laboratories absorb the specified compound from the sample to be analyzed.
There may also be a preliminary filter system to eliminate any traces of soot or uncondensed water from the fumes.

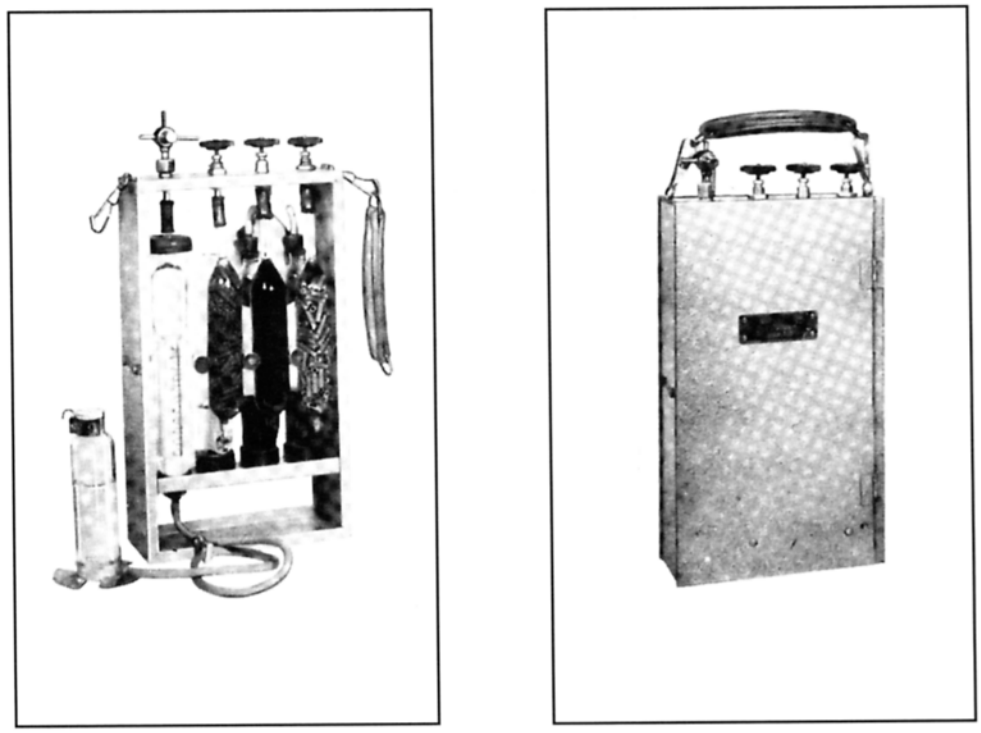

Fig. 6.11a Orsat apparatus for the analysis of flue gases

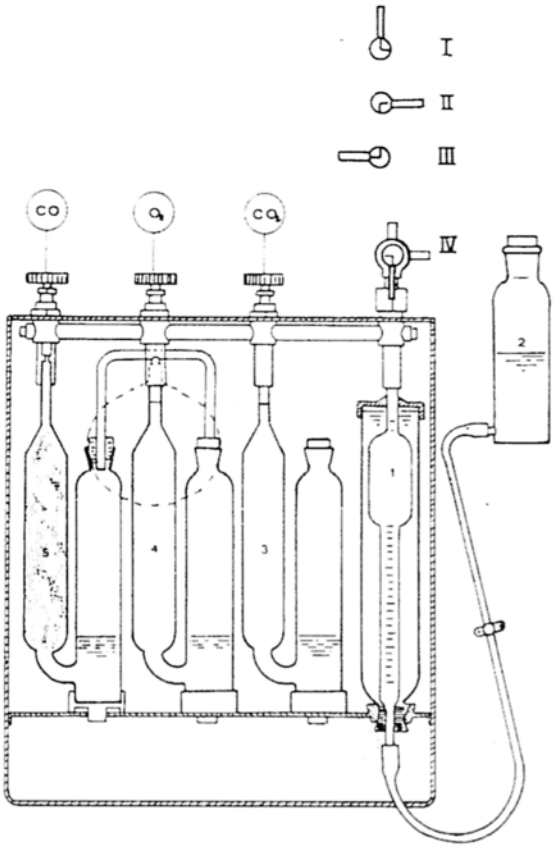

Fig. 6.11b Orsat apparatus for the analysis of flue gases - work scheme

Moving the bottle (2) 100 parts of the fumes to be analyzed are drawn back, bringing the water level in the burette to zero, making sure that pressure is equal to that of the atmosphere thus the water in the bottle must also be reduced to zero at this point. The water used must be acidic to prevent the absorption of CO_2, leading to incorrect results. Moving the three way taps as necessary, the fumes are sent to the first laboratory (3) which contains a solution of potassium hydrate (KOH). This solution is made by dissolving 50g of potassium hydrate in 100 cm^3 distilled water. This solution extracts carbon dioxide and sulphur dioxide. To ease contact and thus absorption, the laboratory is filled with inert material to increase the wet surface. After absorption, the fumes are transfered to the burette (1), making sure that the level of KOH solution is equal to its previous level. The level of water will have risen visibly and this increase is due to the value of the CO_2 and SO_2 absorbed (usually we only talk about CO_2, disregarding the SO_2 because its percentage is negligible). The operation is then repeated in the second laboratory (4) which contains an alkaline solution of pyrogallic potassium which absorbs oxygen. The solution is obtained by dissolving 200g of potassium hydrate in 150 cm^3 water and then dissolving 15 g of pyrogallic acid, also called pyrogallic anhydride in 100 cm^3 of the above solution.
Returning the fumes to the burette (1), the level of the water will rise further indicating the sum of CO_2 and O_2 absorbed. The percentage of O_2 is calculated by subtracting the level of CO_2 already obtained. Finally, the third laboratory (5) is used to absorb any carbon monoxide present, here the reagent is a solution of ammonia and copper chloride, which is obtained by dissolving 250 g of ammonium chloride and 200 g of copper chloride in 750 cm^3 of water and then adding ammonia equal to a third of the above solution. The principle here is the same as in the other two laboratories, but it is necessary to always prepare new solution to avoid exhaustion of the reagent due to use thus making the measurements unreliable. Finally, it is important to make sure all absorptions are complete otherwise unabsorbed parts will falsify the results of the analyses.

Reading example

Extraction and reduction to zero of sample to be analyzed. In the burette (1) there are 100 parts of fumes. If, after the first absorption, the level of water in the graduated burette is 12 there is a 12% volume of CO_2 in the fumes.
If, after the second absorption, the level of water in the fumes is 15.8, that is the sum of CO_2 and O_2 is equal to 15.8%, the percentage of volume of O_2 present is equal to 3.8%, that is, 15.8% - 12% CO_2 = 3.8%.
If, after the third reading, the water level is still 15.8% there is no carbon monoxide present and combustion is complete. In this case there is only nitrogen left in the burette and its percentage volume is equal to 84.2% (100 -15.8 = 84.2).
Fig. 6.12a shows a much simple portable *analyzer.*
It is comprised of two chambers which are connected to a central graduated transparent tube. The lower chamber has an elastic diaphragm at the bottom. The upper chamber, as seen in the figure, has an entrance controlled by a valve to let in the fumes to be analyzed. The valve is coupled to a flexible tube which contains a rubber pear pump with a metal terminal.
The apparatus can be used to determine the percentage volume of CO_2 and O_2 in relation to the absorption solutions used and the measurement scale employed. To carry out the measurement, the metal terminal is placed in the fume duct and, pressing the pump a certain number of times, the fume sample enters the apparatus. In practice two analyzers are needed, one for CO_2 and the other for O_2.
Once the coupling is removed the apparatus is shaken upside down, the measurement is obtained from the height reached by the liquid. By pressing the valve the apparatus is brought back down to zero and is ready to carry out the next measurement.

Analysis of combustion products by physical method

This method uses the different thermal conductivity of the various components of the fumes. If the gas licks an electrically heated wire, the wire is cooled, more or less efficiently, according to the specific heat of the fume's components. Variation of the wire's temperature makes its electrical resistance vary. The apparatus that measures this electrical resistance is calibrated in percentage volume of carbon dioxide. (Fig. 6.13). Thus the reading continues as said percentage or to obtain a diagram, obviously the gas entering the analyzer must be of constant temperature and speed. Similar analyzers are used to determine the level of unburnt substances ($CO + H_2$).

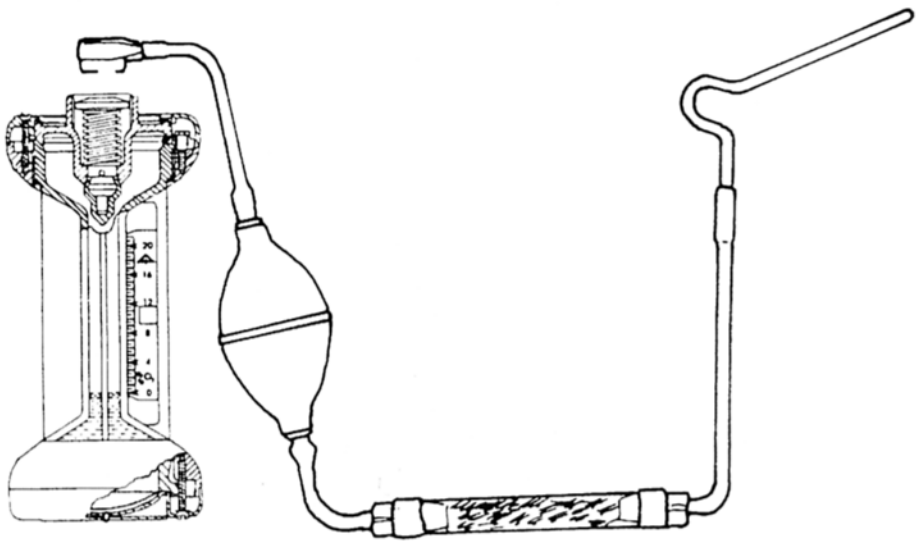

Fig. 6.12a - Portable analyzer

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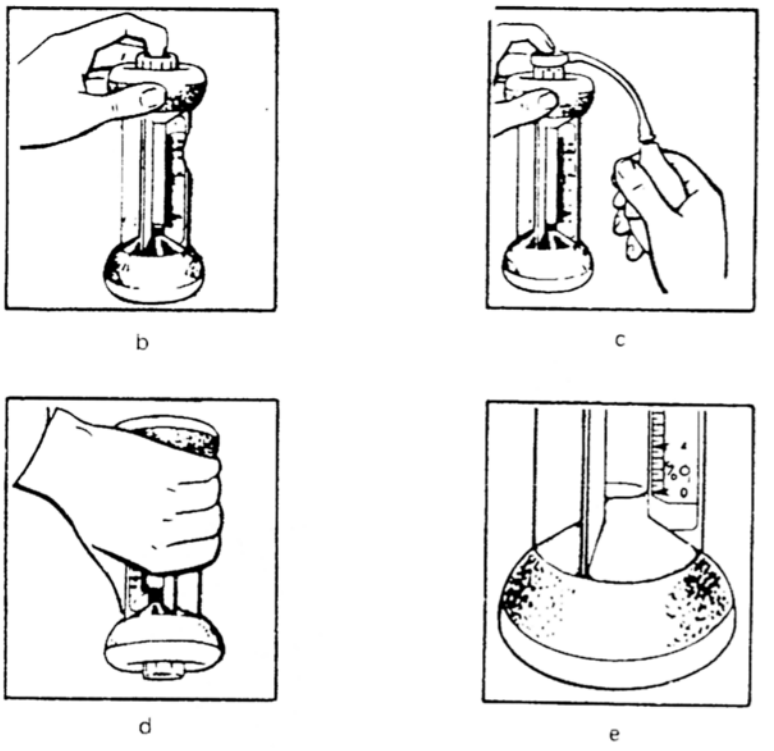

Fig. 6.12b-c-d-e - Different operation with the portable analyzer

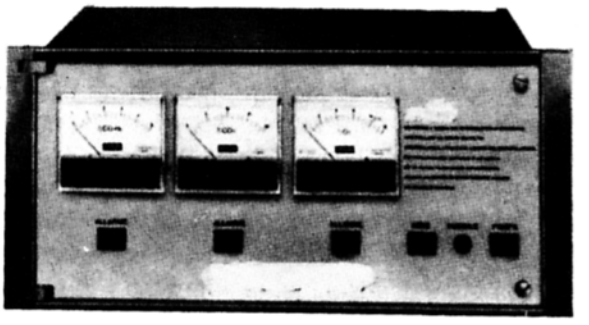

Fig. 6.13 Example of physical flue gases analyzer

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Evaluation of percentage contents of carbon monoxide using the phial system

The apparatus uses special phials containing a granular substance which becomes discoloured on contact with carbon monoxide. The length of the substance that becomes discoloured is in proportion to the quantity of carbon monoxide present (Fig. 6.14).
In this way it is possible to evaluate the percentage volume content of carbon monoxide in the combustion products by passing a certain volume through the phial. Using this method it is possible to reveal the presence of very small traces of carbon monoxide (several parts per million) and thus it is possible to ascertain whether combustion is complete.

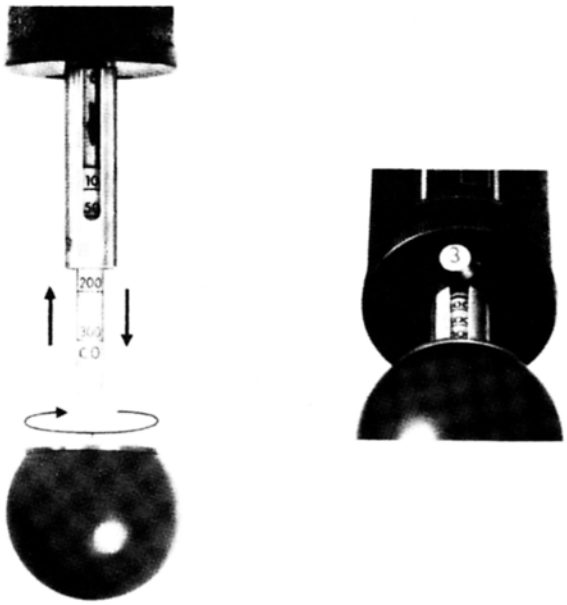


Fig. 6.14 Apparatus to measure carbon monoxide using phial system

THERMOMETERS

Thermometers used for normal uses have already been discussed. In this paragraph, thermometers used in heat generators and pyrometers used for higher temperatures, will be described. To measure the temperature of the fumes in the boiler ducts a glass thermometer with a stem from 0.5 to 1.5m long is used, the stem is protected from knocks by a metal sheath (Fig. 6.15a).

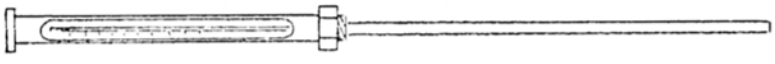


Fig. 6.15a Glass thermometer with long stem

Quadrant mercury thermometer

This is comprised of a metallic bulb filled with mercury and linked, by a capillary tube, to a gauge. In this case, dilations in the mercury cause a variation in pressure which is indicated by the gauge whose scale shows the temperature. (Fig. 6.15b)

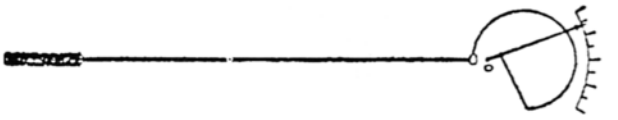


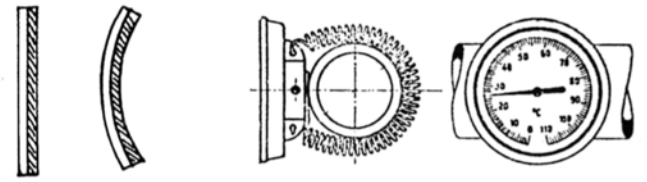
Fig. 6.15b Scheme of quadrant mercury thermometer

Metallic thermometers

These work on the principle of the different thermal dilation of the metals. A bimetallic plate, that is, made of two different metals, is deformed due to variations in temperature. As the plate deforms it causes the movement of the instruments needle (Fig. 6.16). These thermometers exist in different forms and for different applications.

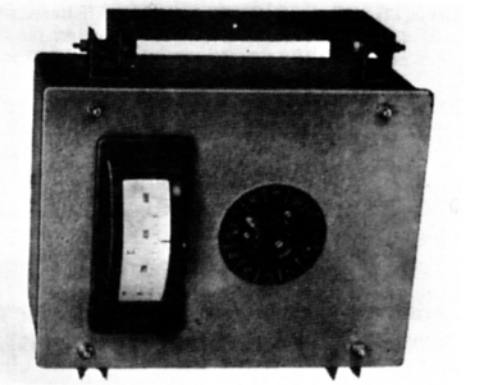
Electrical thermometers

These are comprised of a sensitive element (or sensor) and a measuring instrument (indicator, register or regulator) which are connected by an electric line which can be of considerable length (Fig. 6.17). Thus there is the possibility of carrying out measurements at a distance or using one measuring instrument for several sensors, connected by a manual or automatic switch. The form and dimensions of the sensor can be chosen according to the foreseen applications (temperature of hot and cold water, steam, external and internal environment, combustion chamber, fumes in chimney etc.).



□ Metal having a high coefficient of expansion
▨ Metal having a lower coefficient of expansion

Fig. 16 - Bimetallic strip thermometer



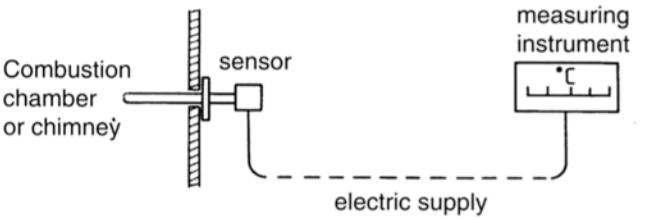


Fig. 6.17 - Remote electrical thermometer

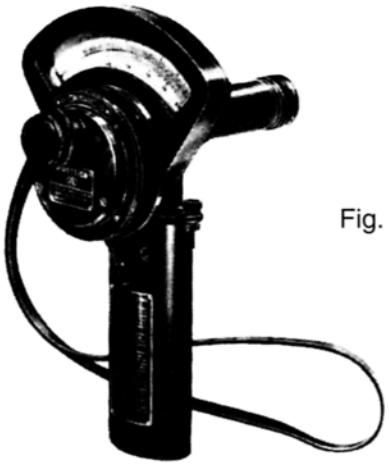


Fig. 6.18

A. Brightness of the filament: low

B. Brightness of the filament: correct

C. Brightness of the filament: high

Optical pyrometers

These are used to measure very high temperatures such as those in the furnace of a generator or an oven. They are used to measure the radiant energy emitted by the bodies. Fig. 6.18 shows one type of optical pyrometer, from the exterior it is very similar to a telescope. Inside there is a lamp whose filament, which is linked to a battery by a variable resistance, lights up. By varying the resistance value, the brightness of the filament can be varied up to the point where its colour becomes confused with that of the body whose temperature is being measured. The intensity of the current, which passes through the lamps filament, is measured by an ammeter whose scale is graded in temperature degrees (Fig. 6.19).

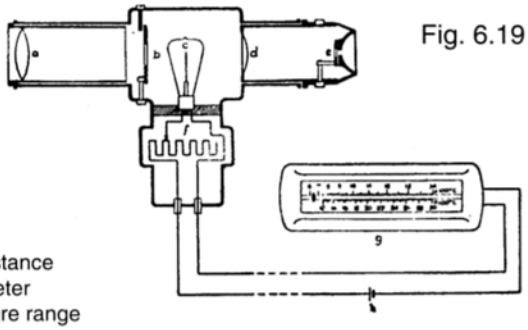


Fig. 6.19

a) Lens
b) Diaphragm
c) Lamp
d) Lens
e) Viewer
f) Variable resistance
g) Setting ammeter for temperature range
h) Battery

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MEASUREMENT OF OPACITY

The most common method involves the use of a paper filter, with pre-established characteristics, which turns black due to the presence of unburnt solids. Though not very precise, this method is used because it is practical. The measurement apparatus is comprised of a pump, to which the paper filter is fixed, by pumping ten times it inhales a predeterrnined volume of fumes. The soot trapped by the filter leaves a round mark on the paper, the darker the mark the larger the quantity of unburnt solids in the fumes. The mark is then compared with ten samples, numbered from 0 to9 with tones increasing from white to black, to deterrnine the Bacharach opacity index (Fig. 6.22). The opacity or fume index at the chimney outlet must not exceed N° 8 on the Bacharach scale. For light oil, the maximum fume index acceptable on the Bacharach scale is 2, for fuel oil it is 6.

Fig. 6.22 Bacarach opacity index measuring apparatus, beside the apparatus is the graduated colour scale sample

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MEASUREMENT OF THE FLOWS

Measurement of fuel quantity - This can be done in different ways according to whether the fuel is solid, liquid or gaseous. Obviously solid fuels can be weighed using scales whilst for liquids and gases various types of meter exist.
Measurement of water entering boiler, feed water - This data is very important for several reasons (purifier regeneration, hot water production etc.), there are various types of water meter (Fig. 6.23).
Measurement of hot water or steamflow - The instruments generally used are based on the measurable difference of pressure in the inflow duct when it is wide and narrow (Fig. 6.24).
The instrument consists of a calibrated diaphragm and flange and a differential gauge which measures the difference in pressure before and after the diaphragm.
The difference in pressure is proportional to the speed of the fluid and therefore also to the flow.
By calibrating the apparatus for a certain fliud it is possible to ascertain the flow.

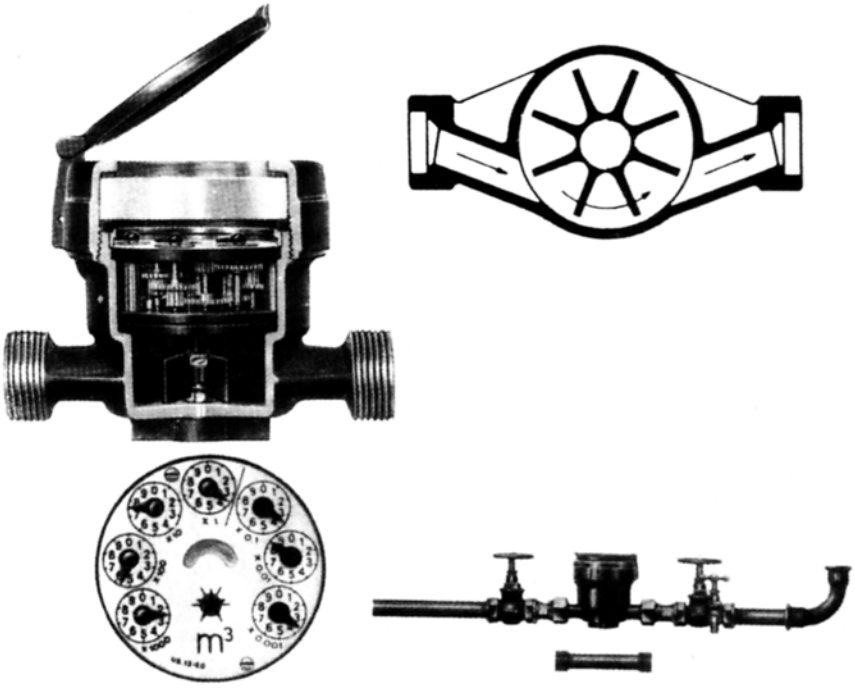

Fig. 6.23

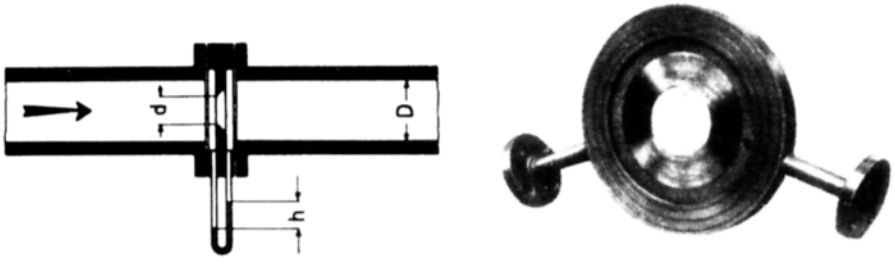

Fig. 6.24

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Thermal control and control of toxic emissions

In this paragraph the control operations, prescribed by the standards in force, to ensure correct working of the plant both from the view of the volume of energy consumption and the effects of pollution are indicated, according to size limits and controlled quantities.

THERMAL CONTROL

Thermal control operations must be carried out according to "Applicative technical specification for the execution of heating plant thermal control operations" described in Enclosure 3 of D.P.R N° 1052 28/06/1977 "Regulation of execution of law N° 373 30/04/1976, relative to energy consumption for thermal uses in buildings." Such operations serve to control the combustion quality and to calculate the percentage quantity of heat lost through the chimney (noticeable heat lost to fumes) and therefore also combustion output (conventional). The tests, which are carried out "in loco" on installed heat generators, involve measurement of combustion air temperature and hot water or vapour exiting, measurement of temperature of combustion products, execution of fume analysis (measurement of percentage volume contents of carbon monoxide and carbon dioxide), measurement of the Bacharach opacity scale and any other necessary measurements. The controls must be repeated three times, using instruments with accuracy required as stated in the above mentioned specification. The percentage quantity of heat lost through the chimney and therefore the combustion output are obtained from the mean value of the controls. The minimum values for heat lost and output are set by D.P.R N° 1052 28/06/1977.* The highest acceptable value for the volume of ca~bon monoxide contained in dry fumes without air is 0.01%, whilst the Bacharach opacity index, limited to liquid fuels, has the following limits: N° 2 for light oil and N° 6 for fuel oil. For the positioning of control apparatus the following is prescribed by standards in force:

- Two holes with diameters of, respectively, 50 and 80mm, with controlled closure used to take samples and application of control apparatus, at the base of the chimney and in the fume ducts connected to the fumace.

- A hole of diameter 50mm at the chimney connection or in the primary duct for the insertion of a fume sample probe and a thermometer for measurement of fume temperature.

Generators with a furnace capacity greater than 1000000 kcal/h (1.16 MW) must be equipped with two pressure measuring instruments, one in the combustion chamber, the other at the chimney base, an instrument to measure the percentage contents of carbon dioxide (CO_2), an instrument to measure the percentage contents of carbon monoxide (CO) or excess oxygen or opacity and an instrument to measure fume temperature, the instruments must be equipped with acoustic alarms. For generators with a capacity greater than 2000000 kcal/h (2.32 MW), the instruments must be able to register continuously the values calculated and finally for generators with a capacity greater than 5000000 kcalfh fume temperature analysis and measurement instruments must be grouped together in one square.

CONTROL OF TOXIC EMISSIONS

Emissions of a plant are defined as those substances which, after the work cycle, are dispersed into the atmosphere.

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In the case of heat generators the emissions are comprised of the following substances:
- Carbon Dioxide (CO_2)
- Carbon Monoxide (CO)
- Sulphur Oxides (SO_2 and SO_3)
- Nitrogen Oxides (N_x O_y)
- Damp air (O_2 + N_2 + H_2O)
- Material particles (Soot and ash)
- Unburnt Hydrocarbons

Some of these substances are defined as toxic, that is they are substances of a nature that can alter the salubrity of air and cause direct or indirect damage on persons or things.The most important pollutants contained in the emissions of thermal plant are sulphur oxides and material particles (dusts and unburnt solids). Standards relative to toxic emissions prescribes the following:

- The opacity index of fumes, at the chimney outlet, must not exceed N° 8 on the Bacharach scale (greater values are acceptable for periods of time no longer than 5 minutes for every hour of working, according to the height of the chimney);

- The fumes must not contain more than 0.25g of solid particles per m^3 of fumes in reference to the dry value and conditions 15°C and 1.013bar;

- The contents of sulphur oxides (SO_2 and SO_3) must not exceed 0.2% when using oil fuel with a viscosity greater than 5°E and sulphur content not exceeding 4%;

- Excluding start up periods, the temperature of fumes at the chimney outlet must be greater than 90°C;

- A volume of between 10% and 13% of carbon dioxide (CO_2) contained in the fumes is considered an indicator of good combustion.

The use of purifiers and dust filters, that is, apparatus for treating combustion products by treating the toxic emissions and reducing composition of fumes within the limits laid out, are controlled by standards in force:

- The use of humid fumes purifiers which dispose of emissions into sewerage or water ways is prohibited;

- The use of dust filters is allowed on condition that cleaning (of cyclones and calm cham,bers etc.) is easy and that the material treated and collected is diposed of in suitable places or delivered to cleansing departments in separate bags, avoiding leakage of the material collected during transportation.

In no way does the use of purifiers and dust filters exempt persons from the observation of limits imposed by legislative measures.